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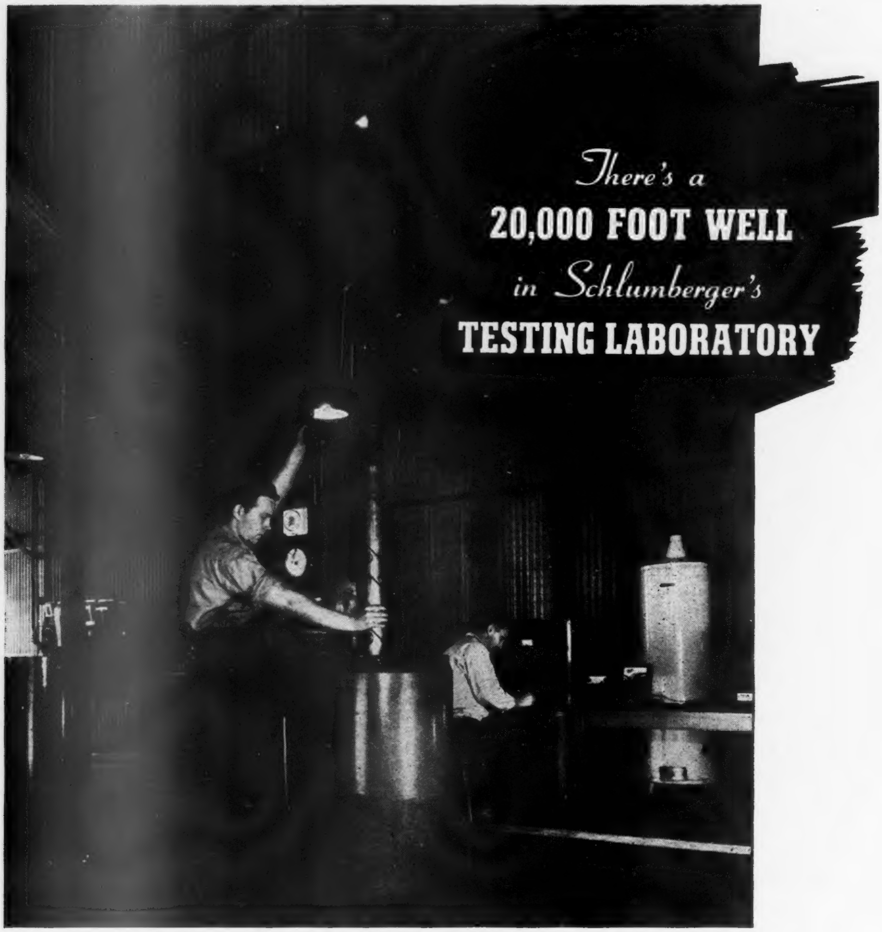
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AUGUST, 1943

STRUCTURE OF CENTRAL TENNESSEE[1]

CHARLES W. WILSON, JR.,[2] AND KENDALL E. BORN[3]
Nashville, Tennessee

ABSTRACT

During the past 10 years many surface and subsurface elevations have been accumulated from several key horizons within that part of Tennessee between Cumberland Plateau on the east and the western valley of Tennessee River on the west. From these data structural contour maps have been compiled on the top of the Chattanooga shale (Kinderhook group of the Mississippian system), on the Pencil Cave horizon (metabentonite bed near the top of the Black River group of the Ordovician system), and on the top of the Knox dolomite group (Cambro-Ordovician system). These maps show the structural configuration of these horizons and permit a study of comparative structure. This comparative study is supplemented by an isopach map of central Tennessee, showing the variations in thickness of the interval between the Chattanooga shale and the Pencil Cave. From these maps many critical facts may be inferred regarding the structural history of the Nashville dome.

INTRODUCTION

PREVIOUS STUDIES

The first structural contour map of the Nashville dome, which occupies much of central Tennessee, was prepared in 1935.[4] The contours were drawn on the top of the Chattanooga shale (Mississippian system) from only about 200 surface elevations and from the scattered existing geologic maps which had been made on topographic bases. On this preliminary map the axis of the dome was indicated entering Tennessee from Kentucky in the central part of Clay County, gradually rising to the crest of the dome in south-central Rutherford County, from which position it split into several minor axes. One of these axes was shown extending southward into the southeastern part of Giles County and into Alabama. Another was indicated trending southwestward into Wayne County and into the northwestern corner of Alabama.

[1] Manuscript received, October 1, 1942. Read before the Association at Chicago, April 11, 1940. Published with the permission of the State geologist, Tennessee Division of Geology.

[2] Vanderbilt University.

[3] Tennessee Division of Geology.

[4] C. W. Wilson, Jr., "The Pre-Chattanooga Development of the Nashville Dome," *Jour. Geol.*, Vol. 43 (1935), Fig. 2, p. 451 and pp. 457–59.

The following year[5] another progress map contoured on the same horizon was published. This map reproduced the Nashville dome essentially as in 1935 but as it was supplemented by an additional 150 surface elevations and several subsurface points, this contour map was extended westward into the western valley of Tennessee River. In the northeastern part of Wayne County two additional axes were indicated, one trending westward through the central part of Hardin County and the other turning to the north through Decatur and Benton counties. This latter axis, which is poorly defined since little control is available, was later referred to as the West-Tennessee arch by Giles.[6] An important structural feature, unnamed by Wilson and Spain although shown for the first time, was the structural "low" that extended into Stewart, Montgomery, Robertson, Houston, and Humphreys counties. This "low" area lies between the Nashville dome on the east and south and the West-Tennessee arch on the west.

Additional data collected between 1936 and 1939 indicated definitely that the major axis of the Nashville dome extends southwestward to the east-central part of Wayne County, where a major split occurs; one branch continues west across Hardin County, whereas the second axis turns northwestward as far as the central part of Decatur County.[7]

PRESENT STUDY

The senior writer collected about 350 surface elevations and a few subsurface points on the top of the Chattanooga shale between 1931 and 1940. During the summer of 1937, while mapping the Stones River and Black River groups in central Tennessee for the Tennessee Division of Geology, he recorded 425 surface elevations on the Pencil Cave (T-3) metabentonite horizon near the top of the Black River group. This work also resulted in the discovery of a well developed northwest-southeast "structural grain" in several counties in the south-central part of the state.

During the same period of time Born recorded about 1,000 surface and subsurface elevations on the top of the Chattanooga shale, about 200 subsurface points on the Pencil Cave horizon, and 60 subsurface tops on the Knox dolomite.

This report, therefore, represents the combined information assembled by both writers during a period of nearly 10 years.

ACKNOWLEDGMENTS

The writers thank Walter F. Pond, State geologist, who sponsored the pre-

[5] C. W. Wilson, Jr., and E. L. Spain, Jr., "Upper Paleozoic Development of the Nashville Dome, Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), Fig. 2, p. 1078 and p. 1077.

[6] A. W. Giles, "Major Structural Features of the Mississippi Valley," in "Contributions to a Knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region," *Geol. Soc. America Spec. Paper 24* (1939), p. 41.

[7] C. W. Wilson, Jr., "Probable Connection of the Nashville and Ozark Domes by a Complementary Arch," *Jour. Geol.*, Vol. 47 (1939), Fig. 2, p. 593, and p. 591.

aration of the report. Many data have been obtained from the subsurface files of the Tennessee Division of Geology. The writers acknowledge their indebtedness to W. B. Jewell for information on Hardin County, to H. D. Miser for data on Wayne County, and to T. E. Weirich, P. S. McClure, E. L. Spain, Jr., and H. B. Burwell for aid in collecting some of the elevations on the Chattanooga shale.

Structural Provinces

NASHVILLE DOME

The Nashville dome is an elliptical dome or swell, which has a concave outline on its northwest side and a convex outline on the southeast. It occupies a position at the southern end of the Cincinnati arch where the axis swings west. The Nashville dome is separated from the Jessamine dome of central Kentucky by a low saddle[8] across the Cincinnati arch, and is apparently separated from the southeastern extension of the Ozark dome[9] by a similar saddle—here termed the McNairy-Hardin saddle—in Hardin and McNairy counties, Tennessee. This latter connection, however, is buried beneath the Upper Cretaceous and Tertiary sediments of the Mississippi embayment.

The history of the Nashville dome during the Paleozoic era was characterized by recurrent subsidence, but everywhere minimum subsidence, for the areas on the east, south, and northwest subsided to a much greater extent. The saddles along the Cincinnati arch between the Nashville and Jessamine domes and between the Nashville and Ozark domes subsided to intermediate positions. The domal structure, therefore, of the Nashville dome has resulted largely from minimum differential subsidence with reference to the surrounding areas, rather than to differential uplift.

FORELAND SLOPE OF APPALACHIAN GEOSYNCLINE

The eastward and southward dips off the Nashville dome merge into the foreland slope of the Appalachian geosyncline. However, within that part of this slope included in the present report, there is only a moderate increase in thickness of sediments rather than the tremendous thickening of sediments characteristic of the deeper part of the geosyncline.

TENNESSEE LOBE OF ILLINOIS BASIN

The structural "low" of Stewart, Montgomery, Robertson, Houston, and Humphreys counties is a southward continuation of the Illinois basin, and is here referred to as the Tennessee lobe of that basin. Its structural history was characterized by recurrent relatively moderate subsidence during the Paleozoic era.

[8] Cumberland saddle. W. A. Ver Wiebe, *Oil Fields in the United States*, p. 103.

[9] C. W. Wilson, Jr., *op. cit.* (1939).

WEST-TENNESSEE ARCH

This structural upwarp has a general north-south trend through Decatur and Benton counties. Although its eastern border coincides with the present western flank of the Tennessee lobe of the Illinois basin, its western limb is practically unknown due to cover by Upper Cretaceous and Tertiary sediments of the Mississippi embayment. It is believed that this arch did not exist at the close of the Paleozoic era, but rather that in this area the strata rose uninterruptedly toward the southwest out of the Tennessee lobe. With the beginning of downwarping in the present embayment area early in the Cretaceous, a reversal of dip was formed along this part of the margin of the embayment by the superimposition of a westward dip upon the older structural rise toward the southwest. The northward continuation of the West-Tennessee arch into Kentucky would coincide with the Cumberland River arch of Jillson.[10] However, at no place do either the West-Tennessee or the Cumberland River arches coincide with the Paleozoic complementary arch that connected the Nashville and Ozark domes, except where they cross at right angles in Decatur and Hardin counties. The West-Tennessee and Cumberland River upwarps are believed to be arches of Mesozoic and Cenozoic age developed along the margin of the Mississippi embayment, rather than Paleozoic arches formed during the earlier tectonic development of the region.[11] Born[12] has indicated that several wells drilled in the Mississippi embayment of Tennessee, down the "western flank" of the West-Tennessee arch, have encountered older Paleozoic rocks than those exposed on the crest of this upwarp.

Structural Contour Maps

INTRODUCTION

In the present study the stucture of central Tennessee is presented by three structural contour maps drawn on the top of the Chattanooga shale (Kinderhook group of the Mississippian system), on the Pencil Cave horizon (near the top of the Black River group of the Ordovician system), and on the top of the Knox dolomite group (Cambro-Ordovician system). Opportunity is therefore offered from comparative structural studies on these horizons of different ages. An interesting comparison may also be made of the relative amount of structural details between these maps as the one contoured on the top of the Chattanooga shale was prepared from 1,500 elevations, the one on the Pencil Cave from 600 points, and the Knox dolomite structure is indicated from 60 subsurface elevations.

[10] W. R. Jillson, "Structural Geologic Map of Kentucky," *Kentucky Geol. Survey*, Ser. 4 (1931).

[11] C. W. Wilson, Jr., *op. cit.* (1939).

[12] K. E. Born, "Paleozoic Wells in the Mississippi Embayment in Tennessee," paper read before the Chicago meeting, American Association of Petroleum Geologists, April 11, 1940.

CHATTANOOGA SHALE

(Fig. 1)

The structural contour map on the top of this horizon was drawn from about 1,500 surface and subsurface elevations. More detail has been shown within the outcrop area of the Chattanooga than in either the Central basin, where outliers of the shale are rare, or down the flanks of the Nashville dome where inliers and subsurface data are irregularly distributed.

The post-Chattanooga crest of the Nashville dome is located in south-central Rutherford County and in northwestern Bedford County where the black shale is about 1,300 feet above sea-level. From this crest the axis may be traced to the northeast through Wilson, Smith, and Jackson counties, leaving the state in the western part of Clay County where the Chattanooga is as low as 650 feet above sea-level. The pitch of the axis in this direction is approximately 10 feet per mile. From the crest the axis trends west-southwest through Marshall, Maury, Lawrence, and Wayne counties. In northeastern Wayne County the axis splits, one branch continuing westward into the central part of Hardin County, where the shale is 550 feet above sea-level, and the other axis extends northwest into Decatur County, where the Chattanooga is as low as 450 feet above sea-level. The pronounced Dunbar structure in the southern part of Decatur County trends north-northeastward across the latter axis.

On the east, the Chattanooga shale dips to 500 feet within the area contoured at an average rate of 15 feet per mile. To the northwest the black shale dips into the Tennessee lobe of the Illinois basin where it is as low as minus 400 feet in Montgomery County. The rate of dip in this direction is about 17 feet per mile. The highly disturbed Wells Creek basin in southeastern Stewart County is contoured diagrammatically since local dips are too steep to be shown with the 50-foot contour interval at the scale of this map.

In Decatur and Benton counties the presence of the West-Tennessee arch is indicated by local closures and partial reversals of dip. In Giles and Lincoln counties, in the south-central part of the state, there is a slight development of a northwest-southeast "structural grain."

PENCIL CAVE HORIZON

(Fig. 2)

Approximately 600 surface and subsurface elevations were used in the preparation of a structural contour map on the Pencil Cave metabentonite horizon near the top of the Black River group. More details are shown within the outcrop area of the Black River group in the Central basin.

The crest of the post-Pencil Cave Nashville dome is located in the south-central part of Rutherford, northwestern part of Bedford, and the east-central part

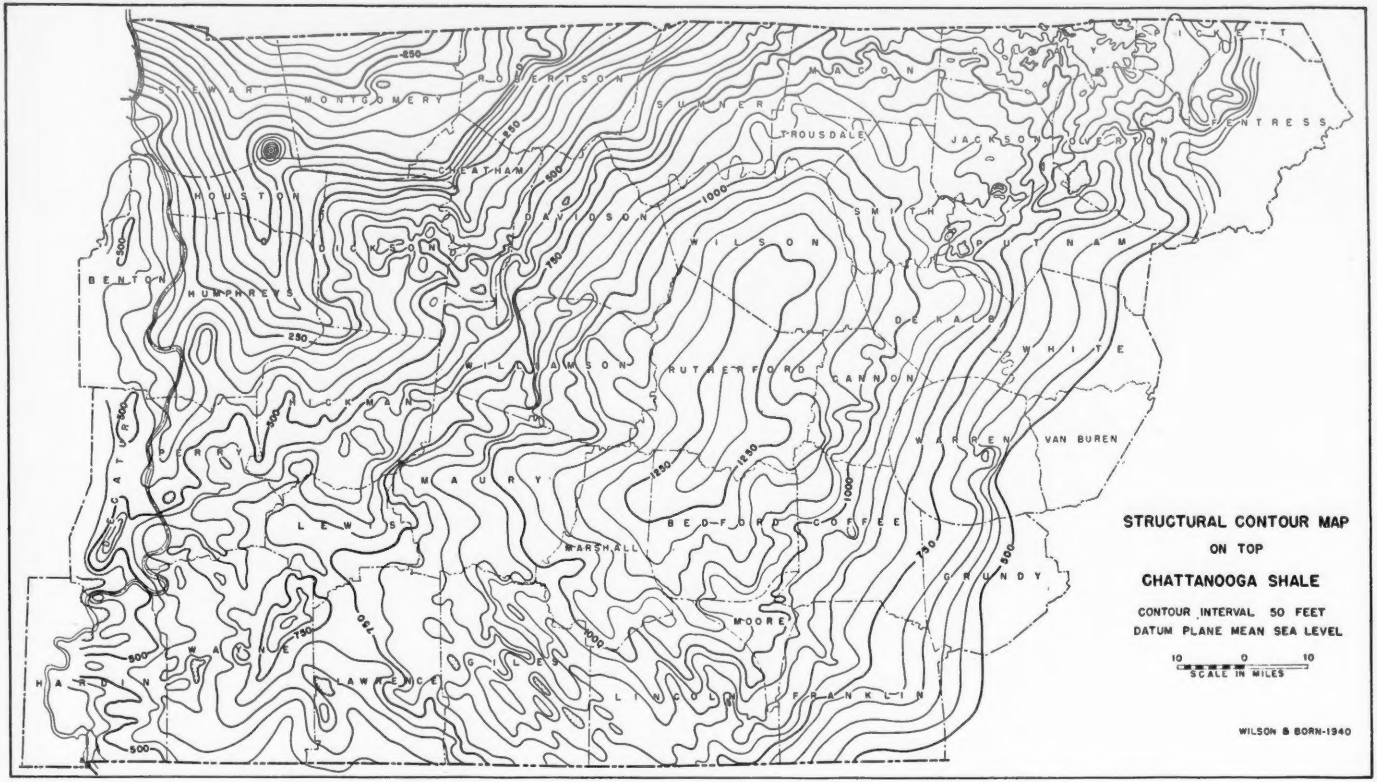

Fig. 1.—Structural contour map of central Tennessee on top of Chattanooga shale.

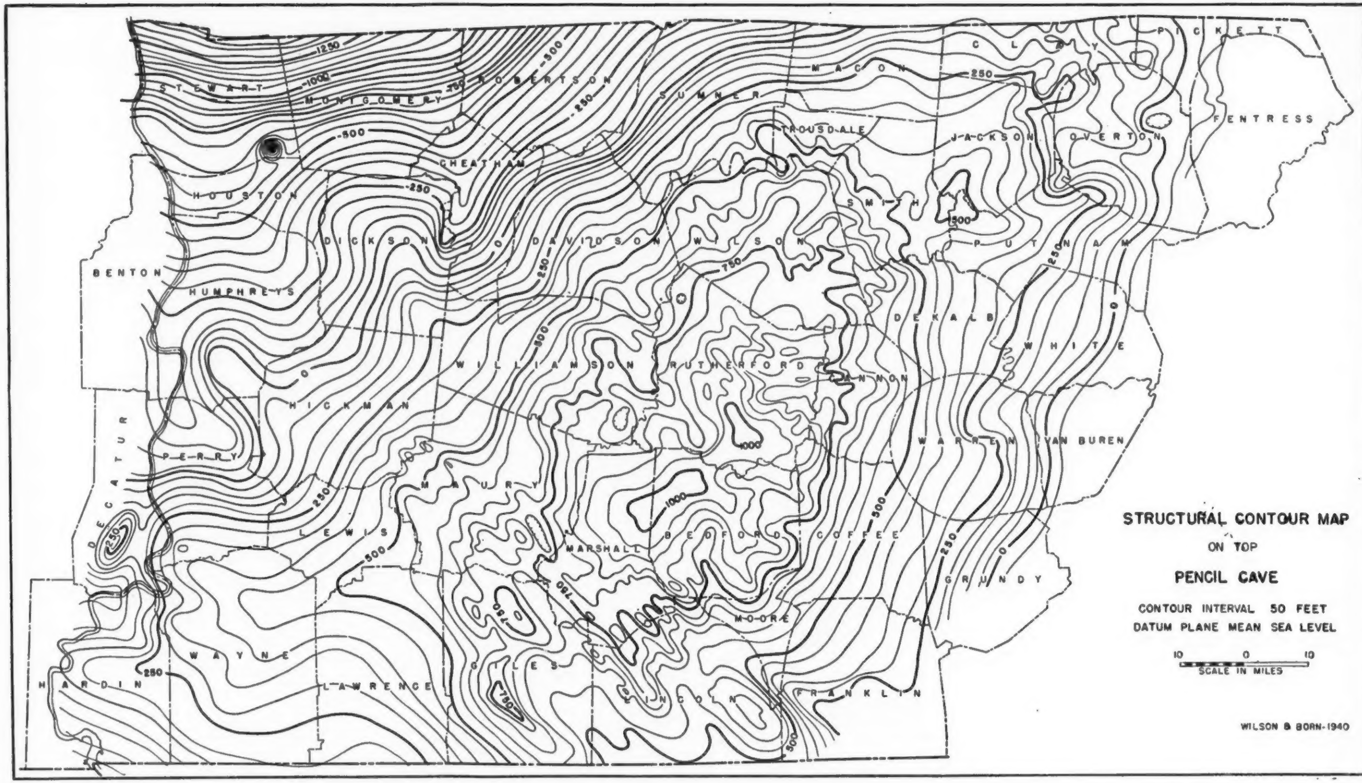

FIG. 2.—Structural contour map of central Tennessee on top of Pencil Cave.

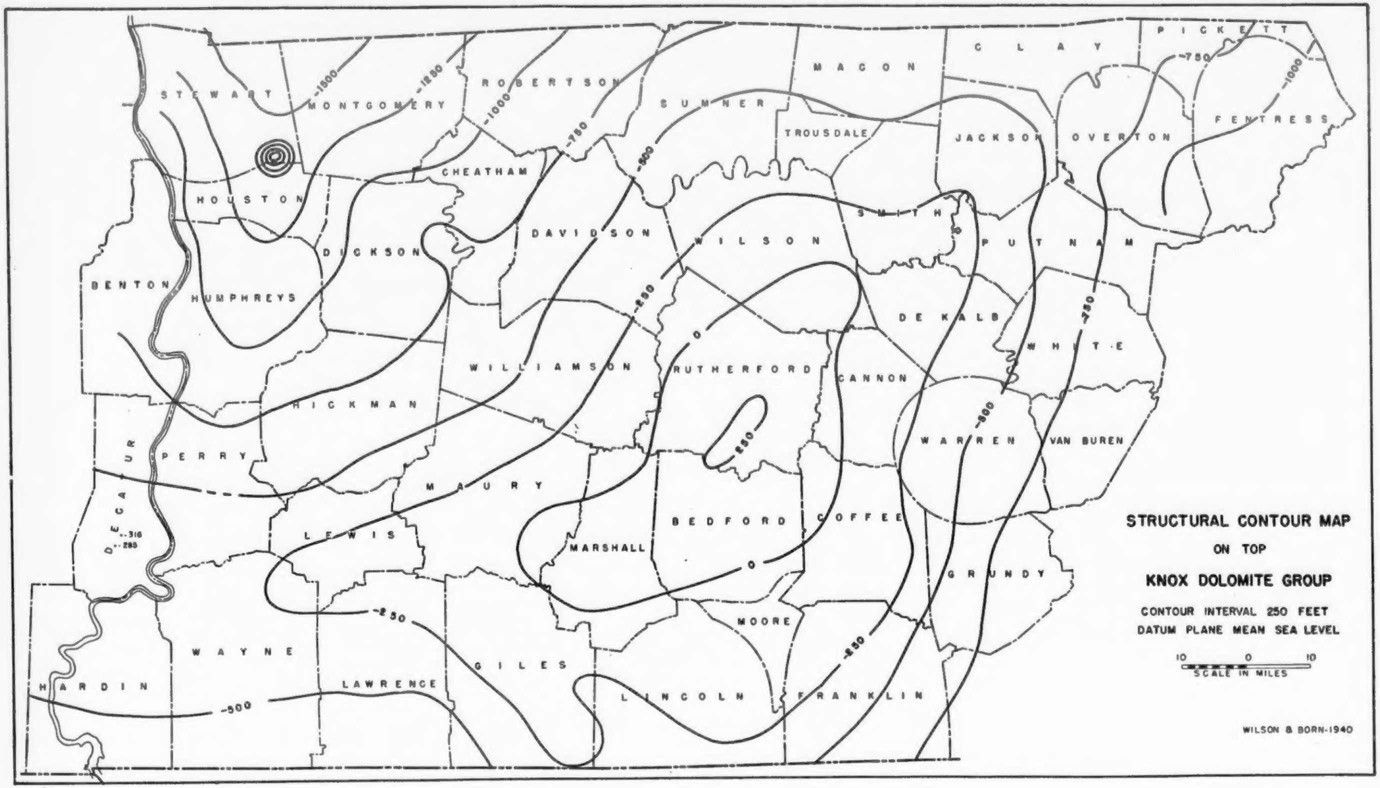

FIG. 3.—Structural contour map on top of Knox dolomite group.

of Marshall counties, where the contoured bed reaches a maximum of more than 1,000 feet above sea-level. From this area the axis trends northeast through Rutherford, Wilson, Smith, Jackson, and the eastern part of Clay counties, where it is about 100 feet in elevation. West-southwest from the crest the Pencil Cave is highest structurally through Maury, Lewis, and Wayne counties. In the northeastern part of the latter county the axis splits into two branches, one extending into the central part of Hardin County, where the Pencil Cave is 150 feet above sea-level, and the other trending into the southern part of Decatur County where the contoured horizon is at about the same elevation.

Eastward from the crest the Pencil Cave dips to 50 feet below sea-level within the area contoured, at a rate of about 20 feet per mile. Northwest of the crest this key bed dips as low as 1,400 feet below sea-level in Stewart and Montgomery counties; the rate of dip is about 22 feet per mile. Again the Wells Creek basin is contoured diagrammatically. No control is available in Decatur and Benton counties which would allow the definition of the West-Tennessee arch.

In the south-central part of the State a pronounced northwest-southeast grain is indicated. The best developed individual structure of this grain is the anticline followed by Richland Creek in the southern part of Giles County. This significant structural orientation is discussed in more detail later.

KNOX DOLOMITE GROUP

(Fig. 3)

The structural map on top of the Knox dolomite group was based on 60 subsurface elevations. For this reason a contour interval of 250 feet was used instead of the 50-foot interval on the Chattanooga and Pencil Cave maps.

The crest of the Nashville dome as shown on the top of the Knox dolomite group is located in the south-central part of Rutherford County where this horizon is approximately 250 feet above sea-level. From this area the axis may be traced north-northeast into Wilson, Smith, Jackson, and Clay counties, where, in the last county, the top of the Knox dolomite group is above 675 feet below sea-level. West-southwest of the crest the axis trends through Bedford, Marshall, Maury, Lewis, and Wayne counties. Structural data do not permit the accurate tracing of an axis which probably trends west of the northeastern corner of Wayne County. In southern Decatur County, however, the Standard Oil Company of Louisiana's C. W. Wyatt No. 1 (2)* and the Chester County Oil Company's J. A. Montgomery No. 1 (1) found the top of the Knox dolomite group at 316 feet and 285 feet below sea-level, respectively (Fig. 3), strongly suggesting the continuation of a part of the axis through southern Decatur County.

Eastward from the crest the top of the Knox dolomite dips at a rate of about 25 feet per mile to a sea-level elevation of −750 feet within the area covered by

* Numbers in parentheses refer to well locations on the insert map in Figure 6.

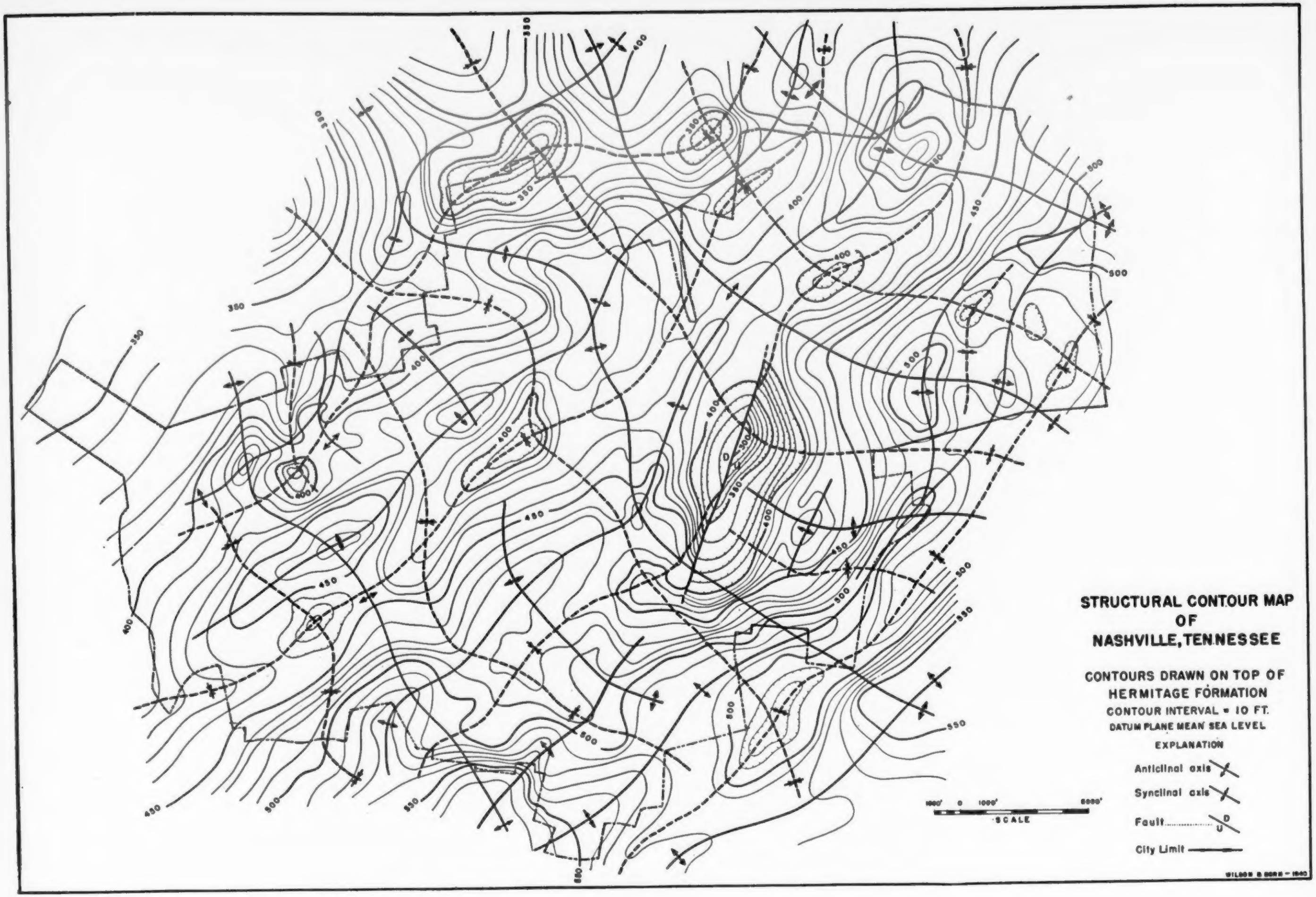

FIG. 4.—Structural contour map of Nashville, Tennessee.

the map. Northwestward the top of Knox dolomite dips, at a rate of 25 feet per mile, into the Tennessee lobe of the Illinois basin where in this State it reaches at least 1,500 feet below sea-level. The Knox dolomite is exposed at the center of the Wells Creek basin and this interesting structure is again contoured diagrammatically.

Structural Grain

In south-central Tennessee, especially in Giles and Lincoln counties, structural work on the Pencil Cave horizon indicates a pronounced structural grain (Fig. 2). The northwest-southeast orientation of the axes of these folds strongly suggests that no direct genetic relationship existed between them and the compressive stresses transmitted west-northwestward from the Appalachian region near the close of the Paleozoic era. From the closely spaced and sharply asymmetrical character of these minor parallel folds it is believed that they resulted from vertical movement along a set of pre-existing northwest-southeast fractures in the rocks of the basement complex. Differential vertical movement along such buried fractures would produce asymmetrical folds by the passive draping of a mantle of sediments over the edges of individual elongated, interfault blocks of the basement rocks as they were being differentially adjusted. As these folds are most strikingly developed along the southern flank of the Nashville dome where the axis of this dome swings from a north-northeast strike to an east-west position, it is believed that the localized accentuation of differential vertical adjustment is definitely associated with the curving of the axis of the dome.

The result of structural studies in the city of Nashville, Davidson County, is believed to illustrate the typical complex structural pattern that is to be expected anywhere in central Tennessee where detailed structure is mapped. Probably at other localities different sets would be more accentuated than the northeast-southwest and northwest-southeast sets found in Nashville, but the same degree of complexity and the same definite controlled pattern is predicted. The description of this pattern, which is shown by structural contour (Fig. 4), is as follows.[13]

> Superimposed upon the northwestward dip are many minor folds that are sufficiently warped to prevent the finding of strata in a horizontal position as originally deposited, Although no elevations were taken in the field, the geology of the city was mapped on an accurate topographic base map, from which elevations could be estimated accurately for the contact between any two adjacent mapped members. These elevations were all reduced to the top of the Hermitage formation by adding or subtracting intervening stratigraphic thicknesses from elevations on older or younger rock units, respectively. Over 500 elevations were thus estimated on a single horizon within the 35 square miles that were mapped. The structural contour map (Fig. 4), made by drawing lines of equal elevation above sea-level on the top of the Hermitage formation, shows a very extensively warped surface. The most obvious generalization to be drawn is the northeast-southwest align-

[13] C. W. Wilson, Jr., "Geology of Nashville," unpublished manuscript.

ment of sinuous axes of anticlines and synclines, along which occur successions of slightly elongate domes and basins, respectively. Adjacent domes along an anticlinal axis are separated by lower structural saddles, and adjacent basins along a synclinal axis are separated by belts of higher structural elevation. A second, somewhat less obvious, generalization to be drawn is that two domes, opposite each other on two adjacent parallel anticlinal axes are usually separated by a belt of higher structural elevation along the intervening synclinal axis; where, two saddles, opposite each other on two adjacent parallel anticlinal axes, are usually separated by a basin along the intervening synclinal axis. This arrangement results in a checkerboard-like pattern of domes and basins, and also in the establishment of the northwest-southeast alignment of sinuous cross-axes of anticlines and synclines. Where a northeast-southwest anticline crosses a northwest-southeast anticline, a dome occurs, whereas when a northeast-southwest syncline crosses a northwest-southeast syncline, a basin occurs. Where a northeast-southwest anticline crosses a northwest-southeast syncline, or where a northeast-southwest syncline crosses a northwest-southeast anticline, a saddle of intermediate structural elevation occurs.

Grain with a northwest-southeast strike, similar to that in south-central Tennessee, was reported by Semmes[14] for several counties in northwestern and north-central Alabama. In 1934 Newcombe[15] discussed the development of several sets of parallel folds in Michigan. The most pronounced and widespread parallel alignment of folds in Michigan is northwest-southeast. A north-south set of folds is present in the southern and north-central part of the state. Northeast-southwest folds occur in the southwestern part, and east-west structures are prominent in the western counties. Newcombe[16] believed that:

The common characteristics of these folds indicate that the deformation in the shallow rocks is related to deep-seated faults in the basement complex. The arrangement of the folds displays the regular pattern and the three dominant directions common to deformation which results from shearing. The exact movement was probably torsional downbending. Downward warping of the basin by forces applied from diametrically opposite directions would cause torsion, and shearing would result. This shearing movement could be localized along lines of pre-existing weakness, but the individual domes would take on the curved outlines brought about by these new stresses. Shearing and unequal subsidence seem to explain the *en echelon* arrangement of anticlinal structures in the central part of the "basin" area.

The close similarity between folds in the Paleozoic rocks in Missouri and fractures in the basement complex is well demonstrated by Graves.[17] Here he reports the two sets of major fractures as striking N. 50° W. and N. 40° E. Minor joint systems are N. 70° W. and N. 20° E., N.–S. and E.–W., and N. 70° E. and N. 20° W. These fractures include faults, flaws, and joints.

[14] D. R. Semmes, "Oil and Gas in Alabama," *Geol. Survey Alabama Spec. Rept. 15* (1929), pp. 73, 100–102, 125, 127, 161.

[15] R. B. Newcombe, "Structure and Accumulation in the Michigan 'Basin' and Its Relation to the Cincinnati Arch," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), Fig. 2, p. 543 and p. 547.

[16] *Ibid.*, p. 555.

[17] H. B. Graves, Jr., "The Pre-Cambrian Structure of Missouri," *Trans. Acad. Sci. St. Louis*, Vol. 29, No. 5 (1938), pp. 111–61.

Relation of Stratigraphy to Structure

COMPOSITE SECTION

A composite stratigraphic section of pre-Chattanooga rocks in central Tennessee follows.

- Devonian system
  - Middle Devonian series
    - (Possibly younger limestones in Tennessee lobe) Onondaga group
      - Pegram limestone
        - *Break*
      - Camden chert
        - *Break*
  - Lower Devonian series
    - Oriskany group
      - Harriman chert
        - *Break*
      - Quall limestone
        - *Break*
    - Helderberg group
      - Decaturville chert
        - *Break*
      - Birdsong shale
        - *Break*
      - Olive Hill formation
        - *Break*
      - Rockhouse shale
        - *Break*
- Silurian system
  - Cayugan series?
      - Decatur limestone
        - *Break*
  - Niagaran series
    - Lockport group
      - Lobelville formation
        - *Break* } Brownsport "formation"
      - Bob limestone
      - Beech River formation
        - *Break*
      - Dixon formation
      - Lego limestone
      - Waldron shale
      - Laurel limestone } Wayne "formation"
    - Clinton group
      - Osgood formation
        - *Break*
  - Medinan series
      - Brassfield limestone
        - *Break*
- Ordovician system
  - Cincinnatian series
    - Richmond group
      - (Possibly Maquoketa shale in the Tennessee lobe)
      - Fernvale formation
        - *Break*
      - Arnheim formation
        - *Break*
    - Maysville group
      - Leipers formation
        - *Break*
  - Mohawkian series
    - Trenton group
      - Catheys formation

Cannon and Bigby formations
Hermitage formation
Break
Black River group
Upper Carters limestone
Metabentonite T-3 (Pencil Cave)
Lower Carters limestone
Break
Chazyan series
Stones River group
Lebanon limestone
Ridley limestone
Pierce limestone
Murfreesboro limestone
Break
Buffalo River group (?)
Zone B[18]
Break
Canadian series
Knox dolomite group (upper)

ISOPACH MAP

(Fig. 5)

In order to show the variations in thickness of the rock units in the preceding tabulation, it was originally planned to make two isopach maps, one of the interval between the top of the Knox dolomite and the Pencil Cave, and the other of the interval between the Pencil Cave and the Chattanooga shale. However, it was found that there were not sufficient subsurface data to prepare the former map at this time, so that only the latter isopach map is presented. Shortly after the beginning of this project the writers became aware of the much greater significance of preparing isopach maps of each individual group of the Ordovician, Silurian, and Devonian systems, and although the necessary data are not sufficient at this time for the compilation of such a series of maps, it is hoped that subsurface studies now in progress will give the information necessary to prepare this series in the near future.

The isopach map showing the thickness of the interval between the Chattanooga shale and the Pencil Cave horizon was prepared from about 200 measurements. Some of these were made on the surface, while others are subsurface intervals. The contour interval of this map (Fig. 5) is 50 feet. The area of greatest thinness occurs in the west-central part of Marshall County and in the southeastern part of Maury County where the interval is about 200 feet. The axis of minimum thinness extends northeastward from this area through Bedford, Rutherford, Wilson, Smith, Jackson, and the eastern part of Clay County, the interval thickening to 500 feet at the last locality. To the west of the area of greatest thinness the axis may be traced into the northeastern part of Wayne County where it splits into two branches, one of which extends through the

[18] K. E. Born and H. B. Burwell, "Geology and Petroleum Possibilities of Clay County, Tennessee," *Tennessee Geol. Survey Bull. 47* (1939), pp. 27–29.

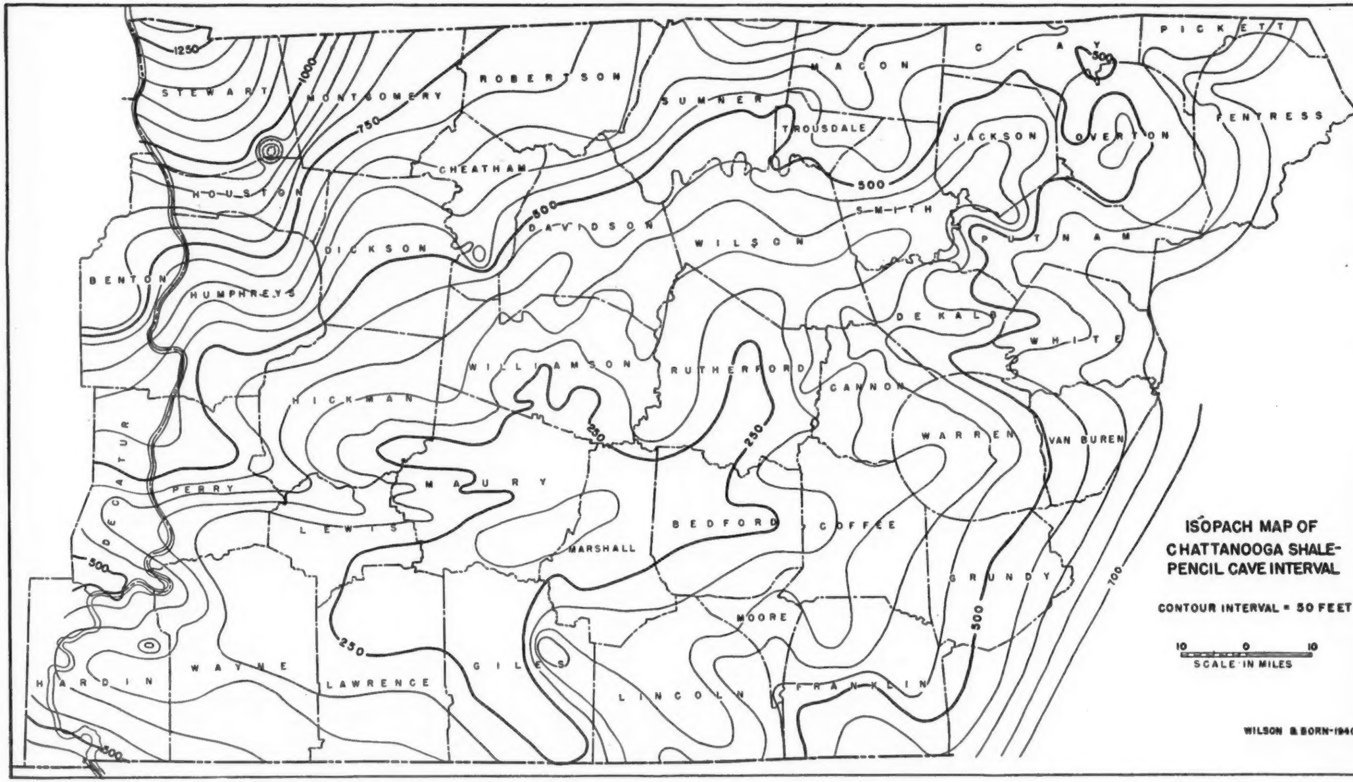

FIG. 5.—Chattanooga shale-Pencil Cave isopach map of central Tennessee.

southern part of Decatur County and the other through the central part of Hardin County. In these two latter areas the interval has thickened to about 450 feet. These two branches are areas where no Devonian rocks are present, rocks of that system occurring in the southern part of Hardin County, in the area between the two branches along the Hardin-Decatur County line, and in the northern part of Decatur County.

Eastward from the area of greatest thinness the contoured interval thickens to 700 feet in the Sequatchie Valley at a rate of 7 feet per mile. Northeastward from the area of greatest thinness the interval thickens at a rate of 12 feet per mile into the Tennessee lobe of the Illinois basin where in Stewart County it is as thick as 1,300 feet. The Wells Creek basin is indicated by diagrammatic "depression" contours as the stratigraphic section at the surface there is abnormally thin due to the intense, local type of deformation that caused this cryptovolcanic structure.

Indications that the pronounced structural grain of south-central Tennessee was in an active state of adjustment during the time of deposition of the Pencil Cave and the Chattanooga shale are definite. Along the anticline that follows Richland Creek in the southern part of Giles County the interval is relatively thin, as is likewise true of the parallel anticline extending through the central part of Lincoln County. Along the syncline in the southwestern part of Lincoln County and in the northeastern part of Giles County, and also along the syncline that extends through Franklin County and the eastern part of Lincoln County, the interval is relatively thick.

STRATIGRAPHIC CROSS SECTION

(Fig. 6)

In order to show graphically the rôle played by the Nashville dome and the associated Hardin-McNairy saddle, the foreland slope of the Appalachian geosyncline, and the Tennessee lobe of the Illinois basin in the control of the variations in thickness of rock units, four composite sections were plotted as being representative of the strata in each of these structural provinces. These plotted sections also give an idea as to the extent and distribution of the various stratigraphic units. The datum plane of the cross section is the Chattanooga shale. No attempt has been made to indicate structure.

The data for these sections were collected from available sources, including both published and unpublished sections measured on the surface and also recorded in the subsurface.

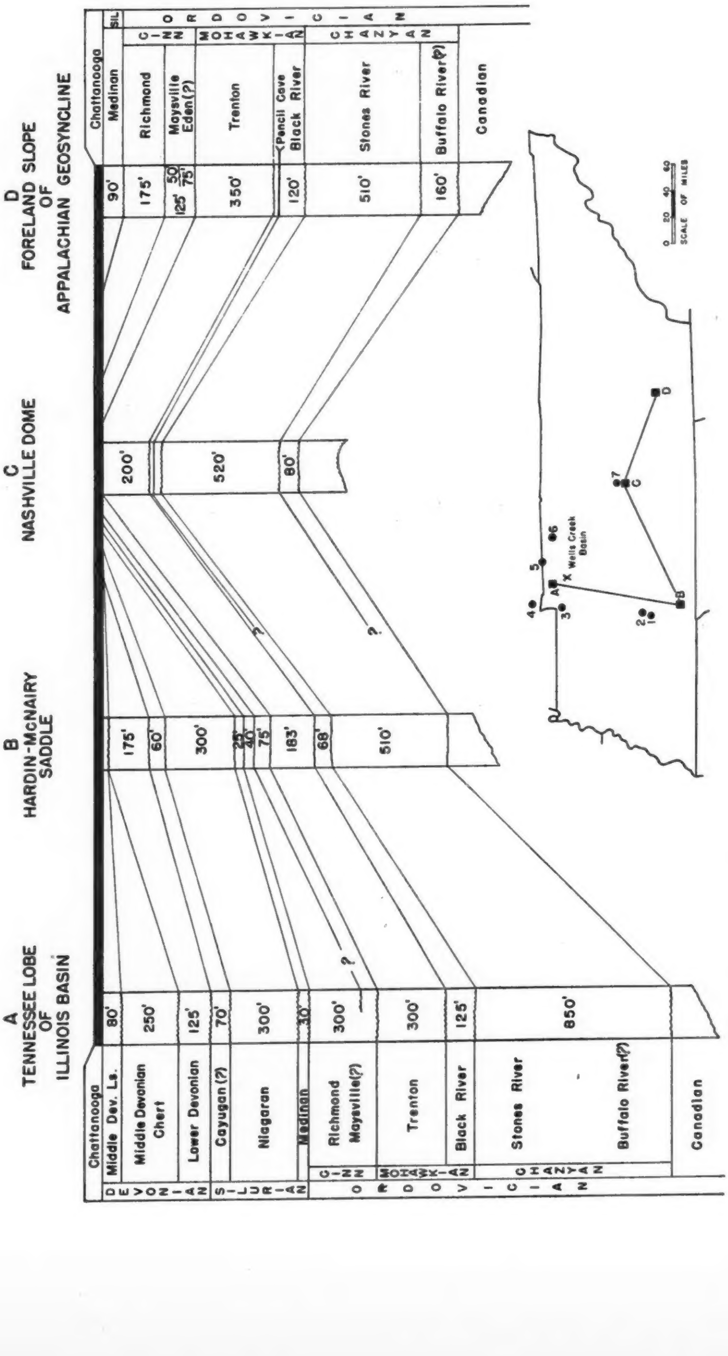

Fig. 6.—Cross section illustrating relationship of structural provinces to stratigraphy of central Tennessee.

SECTION A. TENNESSEE LOBE OF THE ILLINOIS BASIN

ORDOVICIAN SYSTEM

CHAZYAN SERIES

Exposure. Not exposed with possible exception of Wells Creek basin
Thickness. Total of 850 feet for Stones River and Buffalo River groups
Locality. Ada Belle Oil Company's Hillman Land Company No. 2 and 2-A (4),* Trigg County Kentucky
Source. K. E. Born

MOHAWKIAN SERIES

Exposure. Not exposed with exception of Wells Creek basin
Thickness. About 300 feet of "Trenton" and 125 feet of Black River
Locality. Ada Belle Oil Company's Hillman Land Company No. 2 and 2-A (4), Trigg County, Kentucky
Source. K. E. Born

CINCINNATIAN SERIES

Exposure. Not exposed with possible exception of Wells Creek basin
Thickness. About 300 feet most of which, if not all, is Richmond
Locality. Ada Belle Oil Company's Hillman Land Company No. 2 and 2-A (4), Trigg County, Kentucky
Source. K. E. Born

SILURIAN SYSTEM

MEDINAN SERIES

Exposure. Exposed only in Wells Creek basin. Brassfield crops out along northwest flank of Nashville dome (coincides with southeastern limb of Tennessee lobe) between Macon and Wayne counties
Thickness. 30 feet of Brassfield limestone
Locality. Edgoten Oil and Gas Company's Elliott No. 1 (5) Montgomery County, Tennessee
Source. K. E. Born

NIAGARAN SERIES

Exposure. Exposed only in Wells Creek basin. Niagaran formations crop out along northwest flank of Nashville dome from Macon to Wayne counties
Thickness. 300 feet of Lockport and Clinton strata
Locality. Sewanee Oil and Gas Company's Felix Ewing No. 2 (6), Robertson County, Tennessee
Source. K. E. Born

CAYUGAN SERIES?

Exposure. Exposed locally in north part of Tennessee River Valley and in Wells Creek basin
Thickness. 70 feet of Decatur limestone
Locality. Wells Creek basin
Source. W. F. Pate and R. S. Bassler;[19] C. W. Wilson, Jr.

DEVONIAN SYSTEM

LOWER DEVONIAN SERIES

Exposure. Western Valley and Wells Creek basin
Thickness. 125 feet
Locality. Mid-Tennessee Oil Company's A. J. Gray No. 1 (3),* Stewart County
Source. K. E. Born

MIDDLE DEVONIAN CHERT

Exposure. Benton and Henry counties in north part of Western Valley of Tennessee River
Thickness. About 250 feet of Camden chert
Locality. Camden in central Benton County
Source. C. O. Dunbar[20]

* Numbers in parentheses refer to well locations on insert map in Figure 6.

[19] W. F. Pate and R. S. Bassler, "The Late Niagaran of Western Tennessee," *Proc. U. S. Nat. Mus.*, Vol. 34 (1908), pp. 425–26.

[20] C. O. Dunbar, "Stratigraphy and Correlation of the Devonian of Western Tennessee," *Tennessee Geol. Survey Bull. 21* (1919), p. 91.

Remarks. Occurrence of such a thickness of Camden chert on West-Tennessee arch strongly suggests arch was not present in Middle Devonian time, but rather that Benton County was within original extent of Tennessee lobe

MIDDLE DEVONIAN LIMESTONE

Exposure. Pegram limestone crops out within restricted area at "whirl" on Buffalo River, in south Humphreys County, as isolated exposures along west flank of Nashville arch. Well defined in subsurface in Dickson, Montgomery, and Robertson counties
Thickness. About 80 feet
Locality. Edgoten Oil and Gas Company's Elliott No. 1 (5), Montgomery County
Source. K. E. Born
Remarks. Jeffersonville (Onondaga) and Sellersburg (Hamilton) equivalents have been recognized in Pegram at surface.[21] Post-Onondaga strata are undoubtedly present in subsurface

SECTION B. HARDIN-MCNAIRY SADDLE

ORDOVICIAN SYSTEM

CHAZYAN SERIES

Exposure. No exposures
Thickness. Total of 510 feet of Stones River and Buffalo River (?) strata
Locality. Standard Oil Company of Louisiana's C. W. Wyatt No. 1 (2),* Decatur County
Source. K. E. Born

MOHAWKIAN SERIES

Exposure. Trenton group (Hermitage formation) crops out in Hardin, Wayne, Decatur, and Perry counties, reaching maximum of 70 feet at Clifton, Wayne County
Thickness. Total of 251 feet, including 68 feet of Black River beds and 183 feet of strata of Trenton age
Locality. Standard Oil Company of Louisiana's C. W. Wyatt No. 1 (2), Decatur County
Source. K. E. Born

CINCINNATIAN SERIES

Exposure. Maysville strata restricted to Wayne County, but limestone and shale of Richmond group occur more widely in this structural saddle
Thickness. Total of 115 feet of which 40 feet are Richmond and 75 feet are Maysville
Locality. Wayne County
Source. H. D. Miser[22]

SILURIAN SYSTEM

MEDINAN SERIES

Exposure. Scattered exposures throughout saddle
Thickness. 25 feet of Brassfield limestone
Locality. Hardin and Wayne counties
Source. W. B. Jewell[23] and H. D. Miser[24]

NIAGARAN SERIES

Exposure. Widely exposed
Thickness. Total of 300 feet of which 20 feet are Clinton (Osgood formation) and remainder, 280 feet, is Lockport
Locality. Wayne County
Source. H. D. Miser[25]

[21] J. W. Peoples, "The Stratigraphy of the Middle Devonian of the Tennessee Basin," *Trans. Illinois State Acad. Sci.*, Vol. 23 (1931), pp. 431–39.

* Numbers in parentheses refer to well locations on insert map in Figure 6.

[22] H. D. Miser, "Mineral Resources of the Waynesboro Quadrangle, Tennessee," *Tennessee Geol. Survey Bull. 26* (1921), pp. 17–18.

[23] W. B. Jewell, "Geology and Mineral Resources of Hardin County, Tennessee," *Tennessee Div. Geol. Bull. 37* (1931), p. 26.

[24] H. D. Miser, *op. cit.*, p. 19.

[25] H. D. Miser, *op. cit.*, pp. 20–21.

Cayugan series?

Exposure. Scattered exposures
Thickness. 60 feet of Decatur limestone
Locality. Hardin and Wayne counties
Source. W. B. Jewell[26] and H. D. Miser[27]

DEVONIAN SYSTEM

Lower Devonian series

Exposure. Restricted to south part of Hardin County and north part of same county within the limits of Hardin-McNairy saddle. Lower Devonian is absent in central part of Hardin County and south part of Decatur County, areas crossed by the two branches of axis of Nashville dome (Fig. 1)
Thickness. Maximum composite thickness is 175 feet
Locality. Hardin County
Source. W. B. Jewell[28]
Remarks. Attention is called to anomaly of composite maximum thickness of 175 feet in Hardin-McNairy saddle in contrast with 125 feet of strata representing this series in Tennessee lobe. Theoretically, a reversal of these thicknesses would be expected. Either the 125 feet of Lower Devonian strata, logged in Mid-Tennessee Oil Company's A. J. Gray No. 1 (3) in Stewart County, is less than the average in that province or Hardin-McNairy saddle was lower than Tennessee lobe during or immediately following Lower Devonian epoch

Middle Devonian chert

Exposure. The Camden chert does not crop out within area, nor has it been observed in subsurface

Middle Devonian limestone

Exposure. Single isolated exposure
Thickness. 6 feet
Locality. Northern Wayne County
Source. H. D. Miser[29]

SECTION C. CREST OF NASHVILLE DOME

ORDOVICIAN SYSTEM

Chazyan series

Exposure. Stones River strata widely exposed with exception of Murfreesboro limestone, of which only upper 70 feet are exposed. Strata of Buffalo River (?) age (zone B) not exposed, but recognized in subsurface
Thickness. 600 feet. 80 feet of Buffalo River (?) strata and 290 feet of Murfreesboro in subsurface. Surface measurements of remainder of Stones River group total 230 feet
Locality. Basin Oil and Gas Company's Henry Harrell No. 1 (7),* at Murfreesboro, Rutherford County. Surface measurements from several counties in the Central basin.
Source. K. E. Born (subsurface).[30] J. J. Galloway[31] and C. W. Wilson, Jr. (surface)

Mohawkian series

Exposure. Widely exposed in Central basin
Thickness. Trenton group consists of 200 feet of limestone in west-central part of Marshall County and southeast part of Maury County. Black River group includes 30 feet of lower Carters limestone and 10 feet of upper Carters limestone, separated by Metabentonite T-3 (Pencil Cave)
Locality. Rutherford County and parts of adjacent counties
Source. C. W. Wilson, Jr.

[26] W. B. Jewell, *op. cit.*, p. 31.

[27] H. D. Miser, *op. cit.*, p. 22.

[28] W. B. Jewell, *op. cit.*, pp. 31–37.

[29] H. D. Miser, *op. cit.*, p. 23.

* Numbers in parentheses refer to well locations on insert map in Figure 6.

[30] K. E. Born, "Lower Ordovician Sand Zones ('St. Peter') in Middle Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 1646.

[31] J. J. Galloway, "Geology of Rutherford County," *Tennessee Geol. Survey Bull. 22* (1919).

SECTION D. FORELAND SLOPE OF APPALACHIAN GEOSYNCLINE

ORDOVICIAN SYSTEM

CHAZYAN SERIES

Exposure and locality. Sequatchie Valley
Thickness. 160 feet of Buffalo River strata (zone B) and total of 510 feet of Stones River strata
Source. C. W. Wilson, Jr.

MOHAWKIAN SERIES

Exposure and locality. Sequatchie Valley
Thickness. Trenton group commonly about 350 feet thick; Black River group (lower Carters and upper Carters limestones and intervening Metabentonite T-3, or Pencil Cave horizon) is about 120 feet thick
Source. C. W. Wilson, Jr.

CINCINNATIAN SERIES

Exposure and locality. Sequatchie Valley
Thickness. Total of about 300 feet of this series occur, of which as much as 175 feet are Richmond, 50 feet are definitely Maysville, and 75 feet are either Eden (?) or Maysville
Source. K. E. Born and C. W. Wilson, Jr.

SILURIAN SYSTEM

MEDINAN SERIES

Exposure and locality. Sequatchie Valley
Thickness. Composite total of 90 feet occurs, of which lower 50 feet is Brassfield limestone and shale and upper 40 feet of shale is either Brassfield shale or younger
Source. K. E. Born and C. W. Wilson, Jr.

SUMMARY

Four structural provinces have been defined and described in central Tennessee. During the early Paleozoic each was characterized by relative differential movements. The Tennessee lobe of the Illinois basin subsided moderately, the Hardin-McNairy saddle and the foreland slope of the Appalachian geosyncline slightly less, and the Nashville dome subsided the least. These movements were major factors controlling the deposition and preservation of strata in each province. These relationships are well shown by comparing the structural contour maps, the Chattanooga shale-Pencil Cave isopach map, and the stratigraphic cross section.

Variations in thicknesses of the pre-Chattanooga stratigraphic units are believed to have resulted from a combination of truncation by erosion and nondeposition by overlap. The former is considered the more important. Although the major factor was undoubtedly pre-Chattanooga erosion, truncation by other units, especially the Middle Devonian limestone, was appreciable.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 8 (AUGUST, 1943), PP. 1060-1080, 10 FIGS.

BEARING OF FORAMINIFERA AND OSTRACODA ON LOWER CRETACEOUS FREDERICKSBURG-WASHITA BOUNDARY OF NORTH TEXAS[1]

FRANK E. LOZO, JR.[2]
Fort Worth, Texas

ABSTRACT

Lithologic and paleontologic data obtained from an exposure of the Kiamichi and Duck Creek formations are recorded for comparison with that from other areas. From these data certain biostratigraphic observations and paleoecologic inferences are made. The evidence obtained from the distribution of the Foraminifera and Ostracoda points to the conclusion that the Duck Creek is the basal formation of the Washita group of the Comanche series. Evidence for the position of the Middle Albian-Upper Albian boundary at the contact of the Kiamichi and Duck Creek formations is presented.

INTRODUCTION

Since 1887, when the late Robert T. Hill introduced the terms Washita for the uppermost group and Fredericksburg for the next subjacent group of Lower Cretaceous rocks in Texas and Oklahoma, there has been dispute as to whether the Kiamichi is the uppermost formation of the Fredericksburg group or the basal formation of the Washita. A résumé of this dispute through 1938 has been given by M. G. Wilmarth (*1938*, pp. 775–76). Published records since 1938 include those of R. H. Dott (*1941*, p. 1693) and L. W. Stephenson and others (*1942*, p. 444 and plate).

This paper places on record data obtained from an excellent exposure that will soon be inundated and thus impossible to examine in the future. The exposure (Fig. 1) is believed to be the most complete surface section in north-central Texas for the lowermost beds of the Duck Creek formation and probably for the uppermost strata of the Kiamichi. The data consist of the section description; notations of larger fossil occurrences within the section; descriptions, lithologic and faunal, of washed sample residues; and charts of the vertical distribution of the Foraminifera and Ostracoda recovered from the washed samples. From these data certain biostratigraphic observations and paleoecologic inferences have been made. As a result of this study, conclusions about the position of the Fredericksburg-Washita boundary are presented and a suggestion as to the position in north-central Texas of the Middle Albian-Upper Albian boundary is proposed.

For their competent assistance in the collection and preparation of the material, grateful acknowledgment is made to Wanda Yordanoff, Buddy Barron, Owen Cobb, and James Hampton, students at Texas Christian University. Darwin Harbin kindly accompanied the writer during a part of the time spent collecting and supplied the photograph reproduced as Figure 1. E. H. Myers, of the Woods Hole Oceanographic Institution, offered valuable ecologic suggestions. To

[1] Manuscript received, January 7, 1943.

[2] Texas Christian University.

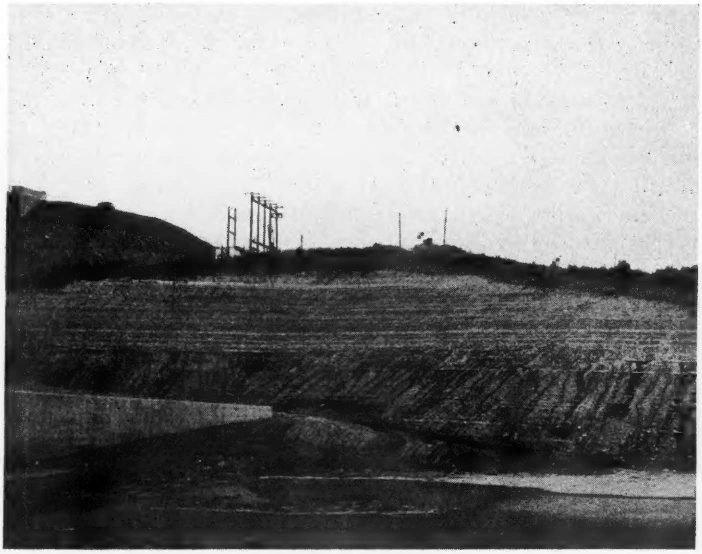

FIG. 1.—Stratification exposure of Texas abutment west of intake structure of Denison Dam, May 23, 1942.

Helen J. Plummer of the Bureau of Economic Geology, Austin, Texas, J. Brookes Knight and Erling Dorf of Princeton University, Hubert G. Schenck of Stanford University, and W. S. Adkins and R. Wright Barker of the Shell Oil Company, Houston, Texas, the writer is indebted for their critical and constructive reading of the manuscript. The writer is especially appreciative of the guidance and encouragement of his colleague, Gayle Scott, throughout the preparation of this report.

DATA

Location of exposure and description of section.—The section described is located approximately 5 miles north of Denison, Grayson County, Texas, at the site of the new dam across Red River (Fig. 2). Excavation on the south bank of the river resulted in a steep bluff more that 100 feet high and exposed at one time the entire thickness of the Kiamichi formation and much of the overlying Duck Creek strata. The Kiamichi is a lithologic unit of black finely laminated fissile shale with thin white limestone members in the lower part and thicker gray-brown shell limestone beds in the upper part. The larger fossils are rare and poorly preserved in the black shale and are commonly found concentrated and compressed in thin bands. The overlying Duck Creek strata are alternate beds of gray marl and white to cream-colored limestone. Larger fossils, particularly ammonites, echinoids, and pelecypods, are abundant. The columnar section

(Fig. 3) summarizes the lithologic succession, the dominant faunal assemblages, and the stratigraphic position of shale and marl samples collected for microscopic examination.

Method of sampling and sample preparation.—The shale and marl samples were collected from trenches dug a foot or more into the excavation to obtain unweathered samples and were so collected that all the softer beds were represented with the exception of the basal 10 feet of the Kiamichi. All samples were thoroughly dried in an electric oven, dashed with cold water while hot, soaked in a 2–5 per cent solution of sodium peroxide, and washed by decantation.

The black shales of the Kiamichi disintegrated fairly easily to particles of

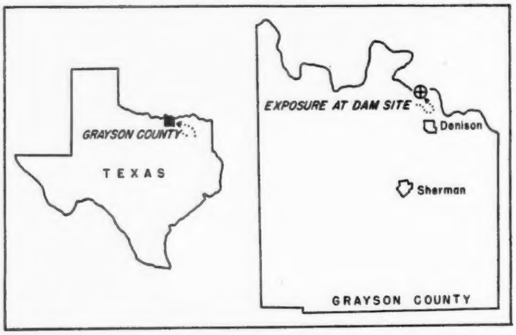

FIG. 2.—Index maps showing location of Grayson County, Texas, and site of Denison Dam.

silt size but these particles did not remain long suspended or disintegrate further. Foraminifera and Ostracoda obtained from these shales were well preserved with the shell material apparently little if any altered. The Duck Creek marls disintegrated easily. The Foraminifera and Ostracoda were well preserved, but many were obscured by occluded spherocrystalline bodies (particularly in the upper beds). In several samples the tests or carapaces appear to be slightly altered by additional microcrystalline calcite.

Descriptions of washed residues.—Approximately 2,500 grams of each sample collected was washed. After washing, the residues of the Kiamichi samples were between 25 and 50 per cent of the original samples. The residues from the Duck Creek samples were considerably smaller and averaged between 10 and 25 per cent of the original volume. About 10 grams of each Duck Creek residue and approximately 25 grams of each Kiamichi residue were subjected to microscopic examination. Annotations of each residue include a lithologic description with the relative amount of each component present, the variety and dominant element of each faunal assemblage, and the relative abundance of the fauna observed with respect to the entire residue. The following terms indicate the quantitative percentage of components mentioned in lithologic descriptions.

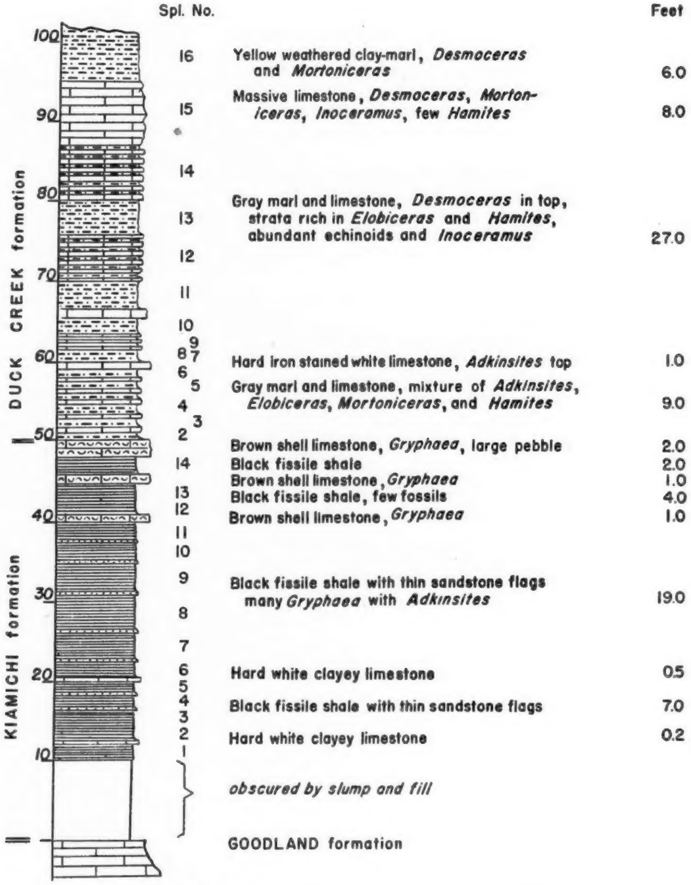

FIG. 3.—Annotated columnar log of Kiamichi-Duck Creek section exposed at Denison Dam.

	Percentage
Abundant	more than 50 of entire residue
Common	50–25
Frequent	24–10
Rare	9– 1
Present	Less than 1 of entire residue

The relative abundance of the fauna observed with respect to the entire residue is listed as very rich, rich, fair, poor, or very poor.

KIAMICHI RESIDUES

Sample 1.—Abundant dark gray shale with very fine sand grains; calcareous cemented sandstone with slightly larger sand grains common; both shale and sandstone contain shell and fish fragmentals; rounded, clear and etched sand grains present.

Fair fauna composed of Foraminifera, fish remains, and ostracodes; Foraminifera dominant almost exclusively *Globigerina*.

Sample 2.—Abundant dark gray shale with fossiliferous sandstone present.

Very poor fauna consisting of Foraminifera, fish remains, and barnacle plates, but none sufficiently numerous to dominate assemblage.

Sample 3.—Abundant dark gray, silty, thinly laminated, slightly calcareous shale with fine micaceous particles; finely crystalline mammillary pyrite concretions present in shale.

Fair fauna of Foraminifera, barnacle plates, fish remains, and ostracodes present; *Globigerina* and arenaceous foraminifers dominate assemblage.

Sample 4.—Lithologic residue as in sample 3 with additional fine and angular-grained, calcareous, micaceous sandstone present.

Fair fauna of Foraminifera, fish remains, and ostracodes; arenaceous Foraminifera dominant.

Sample 5.—Residue as in sample 4 with additional calcareous cone-in-cone fragments present.

Poor fauna composed of Foraminifera, fish vertebrae and scales, and ostracodes; arenaceous Foraminifera dominant.

Sample 6.—Abundant dark gray shale with common brown shale; cone-in-cone fragments present; mammillary pyrite concretions rare.

Very poor fauna of Foraminifera and fish remains; *Virgulina* of the Foraminifera are dominant.

Sample 7.—Dark gray and brown shale as in sample 6 with the brown shale possibly more common; pyrite and cone-in-cone fragmentals absent.

Very poor fauna consisting of fish vertebrae, translucent fish (?) remains, and Foraminifera; fish (?) remains dominate assemblage with *Virgulina* most common foraminifer.

Sample 8.—Abundant dark gray, thinly laminated shale; light gray, very fine and angular-grained, calcareous, micaceous sandstone frequent; concretionary, finely crystalline (pyritohedral) pyrite present.

Fair fauna consisting of ostracodes, foraminifers, gastropods, and pelecypods (pyritic replacements), crustacean chela, and fish remains; ostracodes, particularly *Cytheridea* and *Cytheropteron*, dominate assemblage.

Sample 9.—Lithologic residue as in sample 8.

Rich fauna of same assemblage as sample 8, but with an ammonite (pyritic replacement); *Cytheridea* and *Cytheropteron* of the ostracodes dominant.

Sample 10.—Lithologic residue as in sample 9.

Rich fauna of same assemblage as sample 9; ostracodes dominate assemblage, with *Cythereis* most common genus.

Sample 11.—Abundant dark gray, fissile, thinly laminated shale with very finely dispersed pyrite crystals present.

Fair fauna composed of ostracodes, pyritic internal molds of pelecypods and gastropods, fish teeth, crustacean chela, nacreous shell fragments, and foraminifers; ostracodes, especially *Cythereis* and *Cytheridea*, dominate assemblage.

Sample 12.—Dark gray, fissile shale abundant; tiny pyrite crystals and gray sandy fossiliferous streaks present in shale.

Fair fauna of ostracodes, fish and echinoid remains, and foraminifers present; assemblage dominated by species of *Cytheridea* and *Cytheropteron*.

Sample 13.—Dark gray shale as in sample 12 with tiny pyrite crystals (cubical) present; fossiliferous, slightly calcareous and micaceous, very fine-grained gray sandstone present.

Fair fauna consisting of ostracodes, fish remains, foraminifers, and echinoid spines; ostracodes dominant with *Cytheridea* most abundant.

Sample 14.—Dark gray shale abundant with brown shale as in sample 6 common; nodular, finely crystalline pyrite present.

Very poor fauna consisting mainly of fish (?) remains with a few impressions of Foraminifera and Ostracoda; this sample is poorest faunally of all examined.

Duck Creek Residues

Sample 2.—Residue almost entirely of organic remains; calcareous prisms (aragonite or *Inoceramus* prisms (?)) frequent; slightly sandy argillaceous material rare.

Fair fauna of ostracodes, foraminifers, echinoid, mollusc, and fish remains. Of the Foraminifera and Ostracoda, the latter dominate with *Cythereis* most numerous.

Sample 3.—Gray sandy argillaceous material common, fossiliferous pyritiferous sandy seams frequent.

Fair fauna consisting of ostracodes, foraminifers, pelecypods, fish teeth, and barnacle plates; ostracodes, *Cytheropteron* and *Cythereis*, dominant.

Sample 4.—Residue as in sample 2 with calcareous sandstone and calcareous shale or marl present.

Very rich fauna of ostracodes, foraminifers, pelecypods, barnacle plates, fish teeth and vertebrae and a pyritic ammonite; ostracodes dominant, *Cythereis* and *Cytheropteron* most numerous.

Sample 5.—Residue as in sample 2 with rare gray waxy calcareous shale.

Very rich fauna of Foraminifera, ostracodes, pelecypods, barnacle plates, fish teeth and vertebrae, and bryozoans; Foraminifera dominant and represented largely by Lagenidae.

Sample 6.—Residue as in sample 2 with frequent light-gray, silty, fossiliferous argillaceous material.

Very rich fauna of Foraminifera, ostracodes, pelecypods, echinoderm fragmentals, fish teeth and vertebrae, bryozoans, and pyritic gastropods. Lagenidae dominate assemblage.

Sample 7.—Residue as in sample 6, but with silty gray argillaceous material more common; rare crystalline pyrite concretions.

Very rich fauna of pelecypod and echinoderm fragments, barnacle plates, foraminifers, ostracodes, pyritic snails and ammonites, bryozoans, and fish teeth. Lagenidae dominate Foraminifera.

Sample 8.—Gray and brown shale closely similar to that of Kiamichi residues abundant; dull concretionary pyrite rare; shell fragments present and much fewer than in sample 7.

Very poor fauna consisting of ostracodes, foraminifers, pelecypods, barnacle plates, fish teeth, pyritic snails and ammonites. Ostracodes dominant, *Cythereis* most numerous.

Sample 9.—Organic fragmentals with coherent calcitic spherocrystalline[3] material abundant; dull concretionary pyrite rare.

Fauna poor, consisting of Foraminifera, ostracodes, pelecypods, pyritic snails and ammonites, fish teeth and vertebrae, echinoid and barnacle plates. Foraminifera dominant, Lagenidae and Globigerinidae most numerous.

Sample 10.—Residue as in sample 9, but with less spherocrystalline material and more pyritic concretions.

Fair fauna of foraminifers, ostracodes, pelecypods, pyritic ammonites and snails, barnacle plates, crustacean chela, fish teeth, echinoid remains, and worm tubes; Foraminifera dominant, Globigerinidae and Lagenidae most numerous.

Sample 11.—Residue as in sample 7; crystalline pyrite present, fossiliferous spherocrystalline limestone fragments frequent.

Fair fauna consisting of echinoid plates, pelecypods, foraminifers, ostracodes, barnacle plates, fish teeth and vertebrae. Of the dominating Foraminifera, *Globigerina* is very numerous, Lagenidae and arenaceous forms are common.

Sample 12.—Abundant free spherocrystalline bodies and spherocrystalline limestone; pyrite present.

Very rich fauna of echinoderm fragments, Foraminifera, ostracodes, barnacle plates, fish teeth and vertebrae, pyritic snails, ophiuroid "vertebrae," and crustacean chela. Lagenidae and arenaceous Foraminifera are dominant.

Sample 13.—Gray silty argillaceous material and gray sandstone common; spherocrystalline bodies in white argillaceous limestone common; pyrite as internal molds frequent.

Fair fauna of pelecypod and echinoid fragments, foraminifers, ostracodes, pyritic snails, ammonites, and clams, fish vertebrae, and worm tubes. Foraminifera dominant, arenaceous genera most numerous.

Sample 14.—Abundant argillaceous spherocrystalline limestone with frequent free spherocrystalline bodies, dull concretionary pyrite present.

Very rich fauna of Foraminifera, ostracodes, fish vertebrae, pyritic ammonites and snails, holothurian spicules, echinoid and pelecypod fragments, and worm tubes. Foraminifera of arenaceous species dominate.

Sample 15.—Residue as in sample 14 but with free spherocrystalline bodies more common.

Fair fauna of approximately same assemblage as in sample 14. Ostracodes dominant, *Cythereis* most numerous.

Sample 16.—Tan, silty argillaceous material common, secondary gypsum common, free spherocrystalline bodies very numerous.

Very rich fauna of Foraminifera, ostracodes, pyritic ammonites and snails, fish teeth and vertebrae, pelecypod and echinoid fragmentals, and crustacean chela. Foraminifera dominant, arenaceous species and Lagenidae most common.

[3] References to discussions, figures, and descriptions of these small spherical bodies have been summarized by Adkins (*1932*, p. 365).

OBSERVATIONS AND INFERENCES

Biostratigraphic relations.[4]—It is to be expected that conditions responsible

[4] The terms biostratigraphy and paleoecology as expressions of concepts overlap in the scope of subject treated. Biostratigraphy, as restricted in this paper, implies the actual observable relationships between the faunas and their containing sediments. This includes the factor of chronology, the relative specific and faunal abundance, the present nature of the sediment (whatever the conditions of sedimentation), and the observable presence or absence of associated faunas. Paleoecology, on the other hand, is mostly inferential and implies possible or probable physical, chemical, and biologic factors that may be responsible for the phenomena discussed as biostratigraphic. Modern ecology consists of both observations and inferences and thus includes most of the factors or observations here restricted to biostratigraphy.

FORAMINIFERA	KIAMICHI SAMPLES														DUCK CREEK SAMPLES														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ammobaculites subcretaceus Cushman & Alexander	X		X	X	X						X	X																	
Dentalina debilis (Berthelin)	X			X																X		X		X			X		X
Globigerina planispira Tappan	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X		X	?	X	
" washitensis Carsey	X		X	X		X	X	X	X	X						X	X	X	X	X		X	X	X	X	X	X	X	X
Spiroplectammina scotti Cushman & Alexander	X		X	X	X				X	X																			
Virgulina primitiva Cushman	X		X	X	X	X	X	X	X	X						?	?												
Trochammina depressa Lozo			X	X	X		X																						
Lingulina cf serrata Tappan							X																						
Spiroplectammina cf whitneyi Cushman & Alexander										X																			
Nodosaria cf barkeri Vieaux										X					X				X						X				
Placopsilina longa Tappan															X			X	X	X		X	X	X	X	X		X	
Anomalina aff plummeri Tappan															X	X	X	X	X										
Astacolus comanchensis Lozo															X	X		X	X	X			X	X	X	X			
Frankeina acutocarinata Alexander & Smith															X		X					X	X	X	X	X		X	
Lagena sulcata (Walker & Jacob)															X												X		
Lenticulina washitensis (Carsey)															X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Marginulina cyprina Vieaux															X	X	?	X	X	X		?	X	X	X	?	?	X	
Textularia rioensis Carsey															X					X					X	X	X	X	X
Marginulina tenuissima Reuss																X			X	X			X	X		X	X		X
Textularia washitensis Carsey																?							X	X				X	X
Patellina subcretacea Cushman & Alexander																	X										X		
Spiroplectammina longa Lalicker																	?			X							X		X
Vaginulina aff kochii Roemer /elongate/																	X	X		X									
Bullopora laevis (Sollas)																		X		X									
Palmula acuta Loeblich & Tappan																		X	X	X		X		X					
" leai Loeblich & Tappan																		X	X	X	?	X	?	X	X				?
Vaginulina kochii Roemer																		X	X	X			X	X	X	X	X	X	X
" " var striolata Reuss																		X	X	X		X	X	X	X	X	X	X	X
Anomalina plummeri Tappan																			X	X					X	X	X		X
Ammobaculites goodlandensis Cushman & Alexander																				X							X		
Bigenerina wintoni Cushman & Alexander																				X					X	X	X		X
Bullopora irregularis Lozo																				X									
Frankeina insolita Alexander & Smith																				X							X		
Bullopora cervicornis (Chapman)																						X	X						
Marginulina aff tenuissima Reuss /obese/																						X		X	X		X		X
Palmula leptata Loeblich & Tappan																						?							
Gaudryina subcretacea Cushman																								X				X	X
Tritaxia plummerae Cushman																								X		X			X
Dentalina communis d'Orbigny																									X		X		X
" aff debilis (Berthelin) /striate/																									X	X	X		X
Flabellinella delicata Loeblich & Tappan																									X			X	
Palmula howei Loeblich & Tappan																									X		X		
Flabellinella sp A																										X			
Spirillina cf minima Schacko																										X	X		
Dentalina aff debilis (Berthelin) /gross/																											X		
Nodosaria cf obscura Reuss																											X	X	X
Epistomina aff charlottae Vieaux																													X
Gyroidina cf loetterlei Tappan																													X

FIG. 4.—Distribution chart of Foraminifera recovered from Kiamichi and Duck Creek section at Denison Dam.

for the formation of black shale are sufficiently different from those responsible for gray marl and limestone to influence distinctly the occurrence of nonpelagic life. The larger fossils of the Kiamichi formation, with the exception of *Gryphaea* concentrated in certain limestone strata, are sparser, less varied, and more concentrated in thin lentils than those of the overlying Duck Creek marls and limestones. The foraminiferal fauna of the Kiamichi is much sparser and less varied as to species and genera than that of the Duck Creek, whereas the reverse is true for the Ostracoda. Other microscopic fossils such as barnacle plates, holothurian fragments, bryozoans, and minute crinoids are more common in, if not restricted to, the gray marls.

Distribution of Foraminifera.—The dominant families of Foraminifera (classification of Cushman, *1940*) represented in the black shale facies (other than the pelagic Globigerinidae) are the Textulariidae, Buliminidae (subfamily Virgulininae), and Trochamminidae. This fauna is called the *Virgulina-Trochammina* assemblage. The foraminiferal fauna of the Duck Creek strata is dominated by the Lagenidae, Textulariidae, Lituolidae, Verneuilinidae, and Placopsilinidae. This fauna from the gray marls is termed the *Palmula-Tritaxia* assemblage. The range chart for the Foraminifera (Fig. 4) clearly indicates the sharp paleontologic break between the assemblage from the Kiamichi black shales and that from the Duck Creek gray marls. This is the most profound break in foraminiferal faunas of any contiguous Fredericksburg and Washita formations outcropping in north-central Texas. The two species that occur in nearly all black shale and gray marl samples examined are believed to be pelagic and thus of little value as indicators of bottom conditions.

Distribution of Ostracoda.—A comparison of the ranges shown on the chart of the Foraminifera (Fig. 4) with those of the Ostracoda (Fig. 5) brings out the contrast in relationship of these faunas to the containing sediments. Whereas the Foraminifera of the Kiamichi are distinctly different from those of the Duck Creek, the Ostracoda occurring in the Kiamichi black shales also range up through a certain interval of gray marls. There is thus an overlap of ranges of the "typical' Kiamichi species with those "typical" of post-Kiamichi strata. The beds in which this overlap occurs correspond most closely with those in which "typical" Kiamichi ammonites (*Adkinsites*) and "typical" post-Kiamichi ammonites (*Mortoniceras* and *Hamites*) occur.

Impoverished intervals.—Certain intervals within the section discussed are represented by faunally impoverished samples. This sterility may be almost total (Kki 12 and 14, Kdc 8), confined primarily to the Foraminifera (Kki 11–13), or confined mainly to the Ostracoda (Kki 3–7, Kdc 9–11).

Biotic observations.—Notations on the columnar section (Fig. 3) of the associated larger fossils are here recorded for possible paleoecologic inferences and chronologic significance. With the exception of the *Gryphaea* beds in the upper part, the representation of larger fossils in the Kiamichi is poor. Thin compressed lentils containing the nacreous shells of mollusks, particularly ammonites

OSTRACODA	KIAMICHI SAMPLES														DUCK CREEK SAMPLES														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	2r	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cythereis fredericksburgensis Alexander	X							X	X	X	X	X	X		X	X	X	X	X	X									
" cf dentonensis Alexander	X							X	X	X	X	X	X		X	X	X	X	X	X									
Cytheropteron (E.) semiconstrictum Alexander	X	X		X	X			X	X	X	X	X	X		X	X	X	X		X									
" (".) tumidum Alexander	X							X		X	X	X	X		X	X	X	X	X	X									
Cytheridea amygdaloides (Cornuel)			?					X	X	X	X		X		X		X								?				
" " var brevis (Cornuel)								X	X	X			X		X	X	X												
Paracypris cf siliqua Jones & Hinde									X		X				?														
Cytheropteron (C.) bicornutum Alexander									X	X					X		X										?		
" (E.) howelli Alexander									X				X		X	X	X	X	X	X					X	X	X	X	X
Cytheridea bairdioides Alexander										X	X		X															?	
Cythereis mahonae Alexander													X		X	X	X									X			
" nuda (Jones & Hinde)																	X	X	X						X	X	X		X
" cf carpenterae Alexander																	X			?							X		
Paracypris cf dentonensis Alexander																	X		X	X									X
Brachycythere sculpta (Cornuel)																	X	X	X	X	X				X	X	X	X	X
Cytheridea washitaensis Alexander																		X	X	X					X		X	X	
Cythereis krumensis Alexander																			X	X	X	X	X	X	X		?	X	
" paupera (Jones & Hinde)																									X			X	X
Paracypris cf alta Alexander																									X	X	X		X
Cytherelloidea cf obliquirugata (Jones & Hinde)																										X			X
" cf reticulata Alexander																											X		
Cytheropteron (C.) sp A																											X		

FIG. 5.—Distribution chart of Ostracoda recovered from Kiamichi and Duck Creek section at Denison Dam.

(*Adkinsites*) and clams, have been observed. Rare impressions have also been observed in the black shales. The larger fossils of the Duck Creek are abundant and varied. Echinoids (*Macraster, Hemiaster*), pelecypods (*Inoceramus, Gryphaea* and ammonites (*Adkinsites, Elobiceras, Hamites, Mortoniceras, Desmoceras*) are dominant elements in the gray marls and limestones. The ranges and intervals of abundance of *Adkinsites, Elobiceras, Hamites, Mortoniceras*, and *Desmoceras* are of particular chronologic significance (Fig. 6).

Possible correlative observations.—The lithologic characters and stratigraphic position of the beds poor in Foraminifera and Ostracoda may have paleoecological significance. It has been noted that brown shale occurs in the residues of Kiamichi samples 6, 7, and 14 and in the residue of Duck Creek sample 8. In the Kiamichi particularly it is noticed also that these totally or partially impoverished samples (Kki 2–7, 11–14) are all in close proximity to apparently fairly great sedimentation changes as represented by the white clayey limestone beds in the lower part and the shell-limestone strata in the upper portion. This relationship in the Duck Creek samples (Kdc 8–11) is not so pronounced.

Chronology.—The chronologic factor of biostratigraphy is well illustrated in the Denison Dam section by the vertical ranges of the ostracodes and ammonites. The conclusion as to the boundary between the middle and upper divisions of the Albian, as represented in Texas, is essentially confirmed by the Foraminifera.

Ammonites, in the Lower Cretaceous, are admittedly the most satisfactory fossils for inter-continental correlation of time-stratigraphic units. As stages and zones are independent of lithologic and faunal facies, the fundamental basis for the correlation and subdivision of such units is by the use of fossils such as ammonites that are usually widely distributed regardless of facies factors. Provisional Albian ammonite zones in north-central Texas[5] may be tentatively correlated with similar zones in England[6] as shown in Figure 6. The table indicates that the thinner Gault section is probably less complete, and particularly so, in the interval represented by the Kiamichi and Duck Creek sediments of Texas.

Ostracodes, like the ammonites, are apparently not as greatly affected by ecologic conditions as Foraminifera and are thus better qualified for time-stratigraphic determination. It has already been pointed out that several "typical" Kiamichi ostracode species occur in a basal Duck Creek interval. Several interpretations thus possible for the position of the Middle Albian-Upper Albian boundary are the following.

1. The top of the Middle Albian in Texas may be placed at the highest occurrence of *Adkinsites belknapi* (Marcou), a "typical" Kiamichi marker. This horizon coincides with the highest occurrence of the overlapping Kiamichi ostracode species.

[5] Suggested by Gayle Scott, oral communication.

[6] Compiled by the writer from tables by L. F. Spath (*1923*, p. 4 and *1929*, p. 393).

2. The boundary may be placed at the lowest occurrence of "typical" Duck Creek species and the faunal overlap may be regarded as a persistence of a few tolerant Kiamichi forms during the early period of Duck Creek deposition at the same time that the "typical" Duck Creek and Washita faunas developed. This horizon coincides with the Kiamichi-Duck Creek contact, the lowest occurrence of *Mortoniceras* aff. *trinodosum* (Böse), and the break between the *Virgulina-Trochammina* and *Palmula-Tritaxia* assemblages of Foraminifera.

3. In this section of apparently continuous deposition with an overlap of

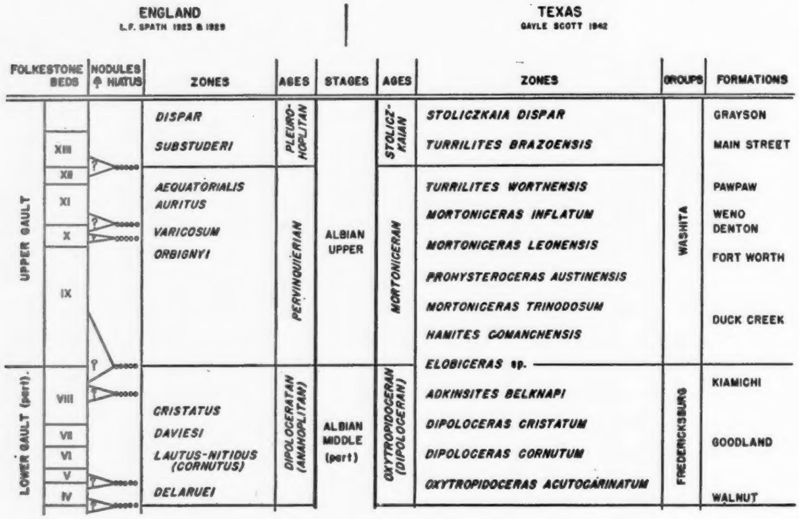

FIG. 6.—Time-stratigraphic correlation table between England and Texas on basis of ammonites.

both large and small fossils, the boundary may be placed within the 10-foot interval of sediments containing the faunal overlap. Yet to be conclusively explained biostratigraphically is the sharp upper limit of such species as *Adkinsites belknapi* (Marcou), *Cythereis fredericksburgensis* Alexander, *Paracypris siliqua* Jones and Hinde, *Cytherelloidea amygdaloides* (Cornuel) var. *brevis* (Cornuel), *Cytheropteron* (*E.*) *tumidum* Alexander, *C.* (*E.*) *semiconstrictum* Alexander, and possibly others. Likewise, the sharp lower limit of occurrence of *Elobiceras* sp.[7] *Mortoniceras* aff. *trinodosum* (Böse), *Hamites comanchensis* Adkins and Winton, *Cythereis nuda* (Jones and Hinde), *C. krumensis* Alexander, *Cytheridea washitaensis* Alexander, and possibly others, deserves consideration. If elsewhere the lithologic facies of upper Middle Albian time were more similar to that of lower

[7] Near Fort Worth (north-central Texas) and Fort Stockton (trans-Pecos region of Texas) *Elobiceras* has been found in the Kiamichi. It is possible that the genus is represented in the Kiamichi at Denison Dam but was not noticed because of poor preservation.

Upper Albian time and a thicker section provided gradational faunal occurrences, this interpretation might be more acceptable.

Until sections of continuous deposition in other areas have been studied in comparable detail, the writer defers final opinion but favors the interpretation that the Middle Albian-Upper Albian boundary be placed at the lowest occurrence of "typical" Duck Creek species of ammonites and ostracodes. It is believed

	ALBIAN				
	MIDDLE			UPPER	
OSTRACODA	Kwa[1]	Kgd	Kki	Kdc[4]	post-Kdc
Brachycythere sculpta (Cornuel)	X	X	X	x X	X
Paracypris cf dentonensis Alexander			X	x X	X
Bairdia roundyi Alexander			X	X	
Cytherella fredericksburgensis Alexander	X	X	X		
Cytheridea oliverensis Alexander	X	X	X		
Cytheropteron (E.) pirum Alexander		X	X		
" (W.) paenorbiculatum Alexander		X	X		
Cythereis cf carpenterae Alexander	X	X	X	x (X)	
" mahonae Alexander	X	X	X	x (X)	
Cytheropteron (E.) howelli Alexander	X[2]	X	X	x (X)	
" (C.) bicornutum Alexander		X	X	x (X)	
Cythereis fredericksburgensis Alexander	X	X	X	x	
Paracypris cf siliqua Jones & Hinde	X	X	X	x	
Cytheridea amygdaloides (Cornuel) var brevis (Cornuel)	X[2]		X	x	
Cytheropteron (E.) tumidum Alexander		X	X	x	
" (W.) semiconstrictum Alexander	X[3]		X	x	
Cytheridea bairdioides Alexander	X[3]		X		
Cythereis cf dentonensis Alexander			(X)[5]	x X	X
" nuda (Jones & Hinde)				x X	X
" krumensis Alexander				x X	X
Cytheridea washitaensis Alexander				x X	X
Cythereis paupera (Jones & Hinde)				X	X
Paracypris cf alta Alexander				X	X
Cytherelloidea cf obliquirugata (Jones & Hinde)				X	X
" cf reticulata Alexander				X	X
Cytheropteron (C.) sp A				X	
" (W.) rugosalatum Alexander				X	X

[1] Includes "sub-Goodland Paluxy" of Vanderpool, *Jour. Paleon.*, Vol. 7, No. 4 (December, 1933), p. 411.
[2] Vanderpool's identifications (*op. cit.*)
[3] Affinis species identified by Alexander in Thompson, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 10 (October, 1935), p. 1516.
[4] Occurrences marked with lower-case x in left column are those from Kdc samples 2–7 of Denison Dam.
[5] Occurrences enclosed in parentheses indicate doubtful identifications.

FIG. 7.—Occurrence chart of selected Ostracoda from Middle Albian and Upper Albian deposits in North Texas.

the appearance of these species accompanied diastrophic changes, the fundamental basis for synchronous correlation.

Figure 7 lists the observed occurrences of species of Ostracoda in the section studied, plus reported occurrences elsewhere of additional species not observed, with reported or observed ranges of all species. With the Middle Albian-Upper Albian boundary interpreted as equivalent to the Kiamichi-Duck Creek contact, that is, at the lowest occurrence of "typical" Duck Creek species of ammonites and ostracodes, the data obtained from the vertical distribution of these ostracode species may be summarized as follows.

1. Thirteen species of the total ostracode fauna (27 species) range from within Middle Albian into Upper Albian. Five of these are typical Middle Albian species

that range upward only to the top of the overlap interval. Four others are typical Middle Albian species that doubtfully occur, as observed by the writer, above the overlap interval. One species typical of Upper Albian is doubtfully identified by the writer and reported from Middle Albian for the first time.

2. Five species are restricted to Middle Albian, only one of which was identified in the Denison Dam section.

3. Nine species are restricted to Upper Albian, only one of which was not identified in the Denison Dam section. Of these, three typical Upper Albian species range from the base of the overlap interval upward.

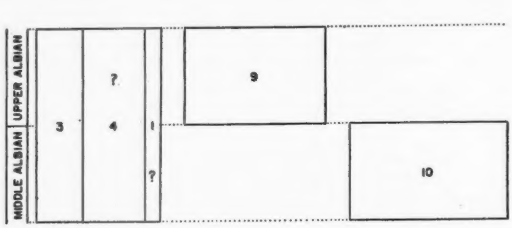

FIG. 8.—Occurrence summary diagram of Ostracoda from Middle and Upper Albian deposits in North Texas.

If all identifications and records are correct, the foregoing summary may be graphically illustrated as in Figure 8. Eight species are of doubtful or little value in placing the faunal break. Nine species are known only from Upper Albian deposits. Ten species are recognized as Middle Albian indicators, of which five are considered tolerant forms that persisted into a very small interval of Upper Albian time. Although the total number of ostracode species analyzed is small, the relative magnitude and sharpness of the faunal break is believed indicative of the time-stratigraphic boundary between the Middle Albian and Upper Albian as represented in north-central Texas.

Foraminiferal affinity.—The writer's studies of Lower Cretaceous faunas in Texas point to the conclusion that benthonic Foraminifera are apparently greatly influenced in abundance and closely controlled in habitat and distribution by the genetic factors responsible for lithologic unity. As a formation is a lithogenetic unit identified "by means of its lithologic character particularly, but also by its stratigraphic association *and its contained fossils*"[8] (Ashley, and others, *1933*, p. 432), it appears as if such Foraminifera should be of value in the determination of relative paleontologic affinities between formations. A group, or lithogenetic unit composed of an assemblage of formations, thus should reflect paleontological affinity among its formations. An analysis of the foraminiferal fauna observed in the Denison Dam section plus known and reported occurrences of other species

[8] Writer's italics.

FORAMINIFERA	FREDERICKSBURG			WASHITA	
	Kwa	Kgd	Kki	Kdc	post-Kdc
Ammobaculites goodlandensis Cushman & Alexander	X	X	X	X	X
" subcretaceus Cushman & Alexander	X	X	X	X	X
Bullopora irregularis Lozo		X	X	X	X
" laevis (Sollas)	X	X	X	X	X
Dentalina communis d'Orbigny	X	X	X	X	X
" debilis (Berthelin)		X	X	X	X
Flabellammina alexanderi Cushman	X	X	X	X	X
Globigerina washitensis Carsey	X	X	X	X	X
Lingulina furcillata Berthelin	X	X	X	X	X
Palmula leai Loeblich & Tappan		X	X	X	
Patellina subcretacea Cushman & Alexander	X	X	X	X	X
Placopsilina longa Tappan		X	X	X	X
Spiroplectammina scotti Cushman & Alexander	X	X	X		X
Textularia rioensis Carsey	X	X	X	X	X
Vaginulina marginulinoides Reuss		X			(X)
Astacolus comanchensis Lozo			X	X	X
Frankeina acutocarinata Alexander & Smith			X	X	X
Globigerina planispira Tappan			X	X	X
Lenticulina washitensis (Carsey)			X	X	X
Lingulina cf serrata Tappan			X		X
Marginulina cyprina Vieaux			X	X	X
" tenuissima Reuss			X	X	X
Nodosaria cf barkeri Vieaux			X	X	X
Virgulina primitiva Cushman			X	(X)	
Ammobaculites laevigata Lozo	X	X	X		
Conorbina conica Lozo	X	X	X		
Lituola inflata Lozo	X	X	X		
Spiroplectammina cf whitneyi Cushman & Alexander		X	X		
Trochammina depressa Lozo			X		
Vaginulina intumescens Reuss	X	X	X		
Anomalina plummeri Tappan				X	X
Bigenerina wintoni Cushman & Alexander				X	X
Bullopora cervicornis (Chapman)				X	X
Flabellammina longiuscula Alexander & Smith				X	X
Frondicularia ungeri Reuss				X	X
Gaudryinella delrioensis Plummer				X	X
Gyroidina cf loetterlei Tappan				X	X
Lagena sulcata (Walker & Jacob)				X	X
Marginulina aff tenuissima Reuss /obese/				X	X
Nodosaria cf obscura Reuss				X	X
Palmula howei Loeblich & Tappan				X	X
Spirillina cf minima Schacko				X	X
Spiroplectammina longa Lalicker				X	X
Textularia washitensis Carsey				X	X
Tritaxia plummerae Cushman				X	X
Vaginulina kochii Roemer				X	X
" " var striolata Reuss				X	X
Anomalina aff plummeri Tappan				X	
Dentalina aff debilis (Berthelin) /gross/				X	
" " " " /striate/				X	
Epistomina aff charlottae Vieaux				X	
Flabellinella delicata Loeblich & Tappan				X	
" plana Loeblich & Tappan				X	
" " var striata Loeblich & Tappan				X	
" sp A				X	
Frankeina insolita Alexander & Smith				X	
Frondicularia hilli Loeblich & Tappan				X	
Gaudryina alexanderi Cushman				X	
" subcretacea Cushman				X	
Palmula acuta Loeblich & Tappan				X	
" leptata Loeblich & Tappan				X	
Vaginulina aff kochii Roemer /elongate/				X	

FIG. 9.—Occurrence chart of selected Foraminifera from Fredericksburg and Washita deposits in North Texas.

elsewhere in north-central Texas should indicate the magnitude of affinity of the Duck Creek Washita fauna with that of the Kiamichi. The inclusion or exclusion, of the Kiamichi formation in, or from, the Washita group, on the basis of foraminiferal affinity, should then be demonstrated.

Figure 9 lists the observed occurrences of species of Foraminifera in the section studied, plus reported occurrences elsewhere of additional species not observed, with reported or observed ranges of all species. The contact between the Kiamichi and Duck Creek formations is interpreted as the boundary between the Fredericksburg and Washita groups. The data obtained from the vertical distribution of these species of Foraminifera are graphically presented in Figure 10 and may be summarized as follows.

1. Fifteen species of the total foraminiferal fauna (62 species or varieties) range from Walnut or Goodland Fredericksburg into Duck Creek or post-Duck Creek Washita. Of this number, only one species, *Palmula leai* Loeblich and Tappan, has not been reported from post-Duck Creek beds and it is common in the Fredericksburg only in Kiamichi that is lithologically similar to the Duck Creek of the section here discussed.

2. Sixteen species are apparently restricted to either the Kiamichi or Duck Creek, only one of which is thought to be confined to the Kiamichi.

These 31 species are of little value for determining the paleontological affinities of either the Kiamichi or Duck Creek.

3. Of the remaining 31 species of the known foraminiferal fauna, 8 species begin in the Kiamichi and range into post-Duck Creek beds. One other, *Virgulina primitiva* Cushman, is known to occur in the Kiamichi and was doubtfully observed by the writer in the Duck Creek but has not been recorded from post-Duck Creek strata.

4. Five species occur in pre-Kiamichi Walnut or Goodland that also occur in the Kiamichi, but not in the Duck Creek or post-Duck Creek.

5. Seventeen post-Duck Creek species occur in the Duck Creek and have not been found in pre-Duck Creek beds.

Recapitulation of the data obtained from the species of affinity value shows that 9 of the 31 species have their earliest occurrence in the Kiamichi and range into Duck Creek or post-Duck Creek strata. Of these 9 species, *Frankeina acutocarinata* Alexander and Smith and *Lenticulina washitensis* (Carsey) have been observed to be common in the Kiamichi only in the very marly facies about two hundred miles south of the Dension Dam section. *Palmula leai* Loeblich and Tappan, doubtfully observed by the writer in the Goodland marls, occurs in marly Kiamichi only, and its distribution probably should be interpreted with the afore-mentioned two species as controlled by the nature of the bottom habitat or the conditions giving rise to the bottom type. The removal of these species, as indicators of paleontological affinity favoring the placing of the Kiamichi in the Washita, would more nearly approximate the percentage relationship of species favoring by affinity the placing of the Kiamichi in the Fredericksburg. This

relatively small percentage, in either case, is not believed sufficient to demonstrate affinity to either group. The most conclusive evidence is that offered by the 17 post-Duck Creek species occurring in Duck Creek but absent in pre-Duck Creek strata. It is primarily on this evidence that it is thought best, solely on foraminiferal affinity, to exclude the Kiamichi from the Washita group and thus place the Fredericksburg-Washita boundary at the base of the Duck Creek formation (Fig. 10).

Paleoecologic deductions.—Many of the probable factors interrelated with the observable faunas and their distribution can not be inferred at the present time. Provisional deductions of several physical, chemical, and biotic interrelationships that may be inferred are placed on record here for comparison with deductions from similar data obtained elsewhere.

Salinity.—The presence and abundance of echinoids, ammonites, and fora-

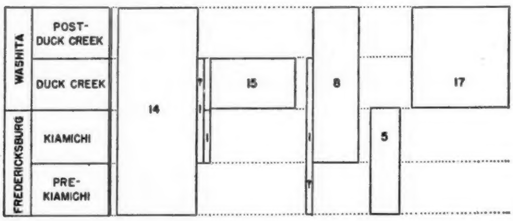

FIG. 10.—Occurrence summary diagram of Foraminifera from Fredericksburg and Washita deposits in North Texas.

minifers of the Duck Creek indicate normal sea-water salinity. In the Kiamichi, echinoid remains are very scarce, ammonites are usually concentrated in thin lentils, and foraminifers are comparatively rare. It is possible that this near-absence of types restricted in general to normal sea-water salinity was the result of brackish conditions during Kiamichi sedimentation. The sudden entry of fresh water may have been responsible for the destruction and concentration of the cephalopods. Although species of *Ammobaculites* and related genera of the Foraminifera are by no means limited to water of low salinity, the common occurrence of these forms under similar conditions in the Gulf of Mexico region to-day suggests an analogous relationship during at least a part of Kiamichi time.

pH of water.—Although empirical alkalinity and acidity (to which salinity is a contributing factor) can not be determined, it is possible that waters covering the Kiamichi bottoms were more acidic than those over the Duck Creek bottoms. Duck Creek Foraminifera were observed to have more massive, thicker-walled tests than those of the Kiamichi. This observation applies also, but to a lesser degree, to the Ostracoda. E. M. Thorp (*1935*, p. 64) remarked that

another factor which influences the distribution of organisms is the alkalinity or acidity of the water in which they live. Foraminifera supply examples of the formation of large,

heavy tests in comparison with quantity of protoplasm, under conditions of high alkalinity. In less alkaline types of water in stagnant bays and at great depths, foraminifera often develop chitinous tests instead of calcareous ones.[9]

Helen Jeanne Plummer (*1925*, p. 19) arrived at the same conclusion in her studies of the Midway faunules. She said

Dr. E. Heron-Allen and Mr. Arthur Earland have shown by experimentation with living forms that with the increase in the salinity of the sea-water the amount of shell material secreted by the protoplasm is correspondingly increased (*Jour. Roy. Mic. Soc.*, pp. 693–695, 1910, and *Phil. Trans. Roy. Soc. London*, ser. B, vol. 206, p. 262, 1915). The various conclusions lead to the obvious conclusion that undoubtedly the early Midway sea carried a higher percentage of calcium carbonate than did the later sea in this period, and this condition may possibly explain in some measure the greater abundance of large fossils in the basal strata of the formation, as well as the characteristically thinner-shelled foraminiferal remains of the upper unit.

Depth.—Cross-bedded sandy limestones were observed in the Kiamichi. Oysters, primarily *Gryphaea*, in countless number are present in the upper Kiamichi. Foraminiferal families dominating the Duck Creek fauna are indicative of greater depths than those most common in the Kiamichi. With regard to Duck Creek Foraminifera from Oklahoma and Texas, Tappan (*1942*, p. 1883) remarked that

an unusually large number of twinned specimens and freaks have been found, of both the calcareous and agglutinated types. Such an occurrence in modern faunas suggests a warm, shallow water environment.

According to E. H. Myers,[10] it is probable that the lower part of the Duck Creek was deposited in water 100–300 fathoms deep, and that the Kiamichi sediments were deposited in shallower water, but not less than 35 fathoms in depth. These limits, based on the distribution of Foraminifera, are somewhat greater than those deduced by Gayle Scott (*1940*) on the basis of ammonites and associated larger fossils. Scott's epi-bathyal (100–80 fathoms) and infra-neritic (80–20 fathoms) represented the Duck Creek; his epi-neritic (20–27 fathoms) division is represented partially by the Kiamichi.

Bottom type.—The interrelationships of sedimentation factors resulting in certain bottom types that directly or indirectly affect the distribution of benthonic organisms are extremely complex and poorly understood. The Kiamichi is composed of thinly laminated, pyritiferous, black shales, with thin sandy members here and there. It is poorly represented with benthonic organisms, has restricted faunal zones of abundance of normally marine animals, and has nektonic or pelagic forms most commonly distributed geographically and vertically. On the basis of these characteristics, the environment of origin of these black shales is interpreted as plant-covered bottoms of tideless or nearly tide-

[9] The evidence on which Thorp bases this statement is not known to the writer.

[10] Personal communication, May 24, 1942. These figures are based on the distribution of comparable, recent Foraminifera taken by Myers.

less shallow epicontinental seas under conditions of poor circulation.[11] In the sediments exposed in Kiamichi outcrops farther south, the evidence shows that these stagnant conditions were less prevalent and the benthonic Foraminifera that lived on or hovered over the marly bottoms are those common in the underlying Goodland marls or overlying Duck Creek marls. These marls and the normal marine environment supported a balanced organic association not represented in the black mud and stagnant environment discussed above.

Biotic factors.—In general, the presence of abundant oysters in North Texas Comanche strata is paralleled by a very poor foraminiferal fauna. The same relationship is not true concerning the ostracodes and oysters. This observation applies to those levels of the Walnut, Kiamichi, and Denton in which oysters are so numerous as to form shell aggregates. R. Wright Barker[12] supplied several Tertiary instances that indicate the same relationship, namely

Ostrea thirsae (Gabb) beds in the Wilcox at Fort Gaines, Georgia, contain very sparse foraminiferal assemblages and fairly good ostracode faunas.

Ostrea thirsae (Gabb) beds in the Sabinetown (Wilcox) of Louisiana contain few or no Foraminifera and fairly good ostracode faunas.

Ostrea sellaeformis Conrad beds in the Claiborne of Little Stave Creek, Alabama, show poorer foraminiferal faunas than the intervening beds, and rather richer ostracode assemblages.

Oyster beds at the base of the Barnwell (Jackson), below the Tivola tongue of the Ocala limestone, at Dry Branch near Macon, Georgia, contain an impoverished foraminiferal fauna and a fair ostracode fauna.

Ostrea westi Mincher bed in the Pascagoula Clay of Mississippi contains a very sparse foraminiferal fauna and a comparatively rich ostracode fauna (Mincher, *1941*, *Jour. Paleon.*, Vol. 15, No. 4, pp. 337–48).

There is little evidence to indicate that the oysters or ostracodes are directly responsible for the resulting scarcity of Foraminifera. It is known that fresh-water ostracodes ingest *Amoeba*, amongst other things,[13] and that certain gastropods and chitins occasionally ingest numbers of Foraminifera while grazing upon algae,[14] but such instances hardly explain the relationship mentioned. It is more probable that physico-chemical conditions favorable to oysters were also favorable to ostracodes, but were decidedly unfavorable to the Foraminifera.

Indirectly, the presence of bacteria and their influence on life in the Kiamichi black shales is strongly indicated. C. E. Zobell and C. B. Feltham (*1942*) on the basis of quantitative data obtained from a study of a marine mud-flat area, have emphasized the importance of bacteria as an ecological factor. Although the Kiamichi is not interpreted as an original mud-flat area, some of the conclusions reached by these authors are believed to apply to certain paleoecologic inferences

[11] For an excellent discussion of this interpretation and other possibilities, see W. H. Twenhofel, *1939*, "Environments of Origin of Black Shale," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 8, pp. 1178–98.

[12] Personal communication, May 19, 1942.

[13] J. Brookes Knight, personal communication, May 25, 1942.

[14] Earl H. Myers, personal communication, May 24, 1942.

made by the writer elsewhere in this paper. Some selected statements of these authors follow.

The hydrogen-ion concentration of the water over mud flats is higher than that of the inflowing oceanic water . . . it is attributed primarily to the production of acidic substances by bacteria. (p. 71)

The oxygen tension of the water over the mud flats is usually decreased in spite of its contact with the atmosphere, another change which is influenced by bacterial activity. (p. 71)

Invariably the bacterial population of the water over the mud flats was higher than in inflowing waters . . . the bacterial population of the water is increased by mud flat conditions. (p. 71)

The mud itself contains many more bacteria than the overlying water. (p. 71)

Bacteria were found in the mud at depths exceeding four meters but most of the samples which were collected for analysis were from the topmost 25 cm. of mud. The latter is the zone of maximum bacterial activity and it is also the principal biotic zone. (p. 72)

Reducing conditions usually prevail below the topmost few centimeters of mud. This, together with the presence of hydrogen sulphide which is often found in a reducing environment, is believed to be the principal factor which limits the depth to which forms of life other than bacteria are found. . . . the absence of certain animals in black mud of high organic content. . . . is probably due to neither the blackness nor its organic content directly but rather to the reducing conditions. (p. 73)

Bacterial activity is believed to be responsible for the reducing conditions in the mud. (p. 73)

These observations of Zobell and Feltham, that bacteria may, despite the dissolved oxygen content, reduce the oxidation-reduction potential, produce hydrogen sulphide, increase the hydrogen-ion concentration, and thus create environmental conditions at certain places which are inimical to other forms of life, seem to describe the environmental conditions prevailing during the deposition of the muds that now comprise the Kiamichi formation.

SUMMARY AND CONCLUSIONS

In the preceding pages the writer has placed on record some observations made from a specific exposure (Fig. 1) that are pertinent to the boundary question between the Fredericksburg and Washita groups of the Comanche series. It is hoped that the observations and deductions may be of value to other workers interested in this and other problems of similar nature. A résumé of these observations and deductions is included in the following statements.

1. The location of the exposure, which will soon be inundated, is about 5 miles north of Denison, Grayson County, Texas (Fig. 2).

2. The section exposed consists of the entire Kiamichi formation (about 50 feet in thickness) and about one-fourth of the overlying Duck Creek formation. Lithologic changes, assemblages of larger fossils and position of samples microscopically examined for smaller fossils are noted in the columnar section (Fig. 3).

3. The methods of sampling (channeling) and sample preparation (decantation) are described and annotations of washed sample residues are listed.

4. Distribution charts of the Foraminifera and Ostracoda obtained from this section have been prepared (Figs. 4 and 5).

5. Biostratigraphic relations concerning the distribution of Foraminifera, Ostracoda, impoverished intervals, observations possibly correlative with these impoverished intervals, and the distribution of associated larger fossils have been recorded. Further, the known ostracode faunas as observed in this section and reported from elsewhere have been charted (Fig. 7) and analyzed (Fig. 8) for their chronologic value in confirming the probable Middle Albian-Upper Albian boundary as determined on the basis of ammonites (Fig. 6). Likewise, the known foraminiferal faunas have been charted (Fig. 9) and analyzed (Fig. 10) for affinities indicating the probable Fredericksburg-Washita boundary.

6. Paleoecologic deductions from the observations have been made. Special attention is given to probable biotic factors, salinity, depth, hydrogen-ion concentration, and bottom type which probably have influenced the distribution of the Ostracoda and Foraminifera.

From these observations and deductions, the major conclusions are these.

1. There is no conclusive physical evidence of a hiatus at this locality between the Kiamichi and Duck Creek formations and deposition is believed to have been continuous. The presence of certain ammonites and their interrelationships indicate a more complete paleontological section here than elsewhere along the North Texas outcrop.

2. The sediments that now form the Kiamichi formation, for the most part, were deposited in an environment of shallow, tideless or nearly tideless, epicontinental seas under less saline, more acidic, more stagnant, and shallower seas than the overlying Duck Creek sediments. This environment could have been produced by a regressing sea.

3. The Ostracoda are not affected so greatly by the bottom-sediment factor as are the Foraminifera and are thus more useful as chronologic indicators, at least in the stratigraphic section discussed. Percentage relationships of the Ostracoda and corroboratory occurrences of certain ammonities indicate a definite paleontological time break here correlated with the basal boundary of Upper Albian or Vraconnian of the standard European time scale. The boundary in the section discussed is at the contact of the Kiamichi and Duck Creek formations.

4. Percentage relationships of the Foraminifera from the Kiamichi do not indicate a decided affinity with either undisputed Duck Creek Washita or undisputed Goodland Fredericksburg. Inductively, that is, because the Duck Creek contains such an abundant foraminiferal fauna with many species ranging well into if not throughout the post-Duck Creek Washita, and with many genera that do not occur in pre-Duck Creek strata it is concluded that the base of the Duck Creek formation is also the lower limit of the Washita group. Discounting the occurrence of "typically" Fredericksburg ostracode species in the lowermost 10 feet of the Duck Creek, the Fredericksburg affinity of Ostracoda occurring in the Kiamichi is decidedly affirmative. Similarly the "typically" Washita

species range into the Duck Creek and no lower. Deductively, on the basis of ostracode affinities, the Kiamichi is the uppermost formation of the Fredericksburg group.

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GROUND WATER AND RELATION OF GEOLOGY TO ITS OCCURRENCE IN HOUSTON DISTRICT, TEXAS[1]

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ABSTRACT

The geologic formations from which the Houston district obtains its water supply are upper Miocene, Pliocene, and Pleistocene in age. These formations are continental in origin and consist of interbedded sand, clay, and gravel. The section has been subdivided into seven zones by electrical logs. The annual pumpage in the Houston and Pasadena areas was nearly constant from 1930 to 1936 but increased about 60 per cent between 1937 and 1941. From 1930 to 1936 the water levels were in approximate equilibrium. The large increase in pumpage caused a marked decline in the water levels. In the Katy area the annual pumpage decreased somewhat from 1930 to 1935, but increased more than three-fold from 1935 to 1940. There has been a net decline in water levels over several years. The quality of the ground water used in the district compares favorably with other supplies in the United States. Data from exploratory drilling show that an additional supply of ground water is available west and north of Houston, and that salt-water encroachment from down the dip is not likely to occur for at least many years.

INTRODUCTION

The Houston district, as the term is used in this report, comprises Harris County west of the San Jacinto River and adjoining parts of Montgomery, Waller, and Fort Bend counties (Fig. 1). In this district large quantities of ground water are pumped from three areas: (1) the Houston area, which includes the city of Houston and the areas immediately adjacent, except on the east; (2) the Pasadena area, which includes the industrial section that extends along the ship channel from the Houston city limits eastward to Deer Park; and (3) the Katy area, which is a rice irrigation area of about 300 square miles roughly centered at the town of Katy, 30 miles west of Houston.

An investigation of the ground-water supply of the Houston district has been in progress since December, 1930, when funds have been available, by the Geological Survey, United States Department of the Interior, in coöperation with the Texas State Board of Water Engineers and the City of Houston. This investigation has from the beginning been under the direction of W. N. White, of the Geological Survey, and the general supervision of O. E. Meinzer, geologist in charge of the Ground-Water Division of the Survey. The results of the investigation have been summarized in eight mimeographed progress reports, and published by the Texas State Board of Water Engineers, the first in October, 1932, and the last in January, 1942. The current phase of the investigation was begun in the fall of 1938 and the field studies of this part of the investigation were made by W. F. Guyton and the writer, assisted at various times by other members of the Geological Survey and the Texas State Board of Water Engineers.

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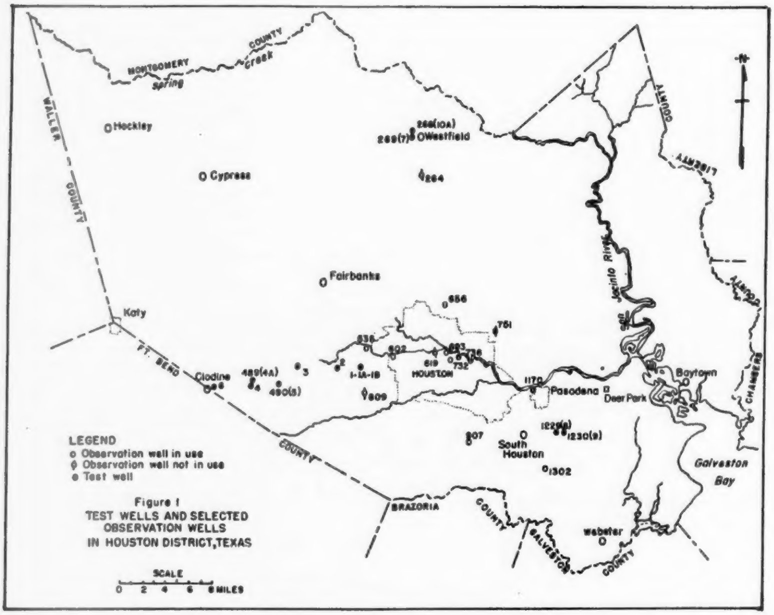

Figure 1
TEST WELLS AND SELECTED OBSERVATION WELLS IN HOUSTON DISTRICT, TEXAS

History of Ground-Water Development

The Houston Water Company, an independent agency organized to furnish the public water supply for Houston, drilled its first well in June, 1888. According to Singley[3] this well was 140 feet deep, contained 15-inch casing, and originally had a flow of more than 1,000 gallons a minute. From June, 1888, to May, 1905, 65 wells, ranging in depth from 115 to 1,330 feet, were drilled by the Houston Water Company on a 14-acre tract along Buffalo Bayou, near the Central Pumping Plant of the present Houston Water Department. Although all the wells had a flow, most of them were equipped with airlift pumps as early as 1899. In October, 1906, the city of Houston purchased the Houston Water Company, which at that time had 45 flowing wells, 36 of which were equipped with airlift pumps. The capacity of the 45 wells in 1906 was 19 million gallons a day and the average daily pumpage was about 11 million gallons. By 1935 all of these wells had been abandoned and sealed. In 1942 the public water supply of Houston was furnished by 23 wells, which ranged in depth from 777 to 2,041 feet and had a capacity of about 51 million gallons a day. The average daily pumpage in 1941 was 27 million gallons.

[3] J. A. Singley, "Preliminary Report on the Artesian Wells of the Gulf Coastal Slope," *Texas Geol. Survey 4th Ann. Rept.* (1893), p. 106.

The Houston ship channel was opened to ocean-going vessels in August, 1915. The Galena Signal refinery, now The Texas Company refinery, was the first large consumer of ground water in the Pasadena ship-channel area. The refinery began operating in 1916 and was followed by the Sinclair refinery in 1919, the Crown Central refinery in 1920, the Deep Water plant of the Houston Lighting and Power Company in 1923, the Shell refinery in 1926, the American Petroleum Company in 1931, and the Champion Paper and Fibre Company in 1937. Since 1939 several other industrial plants have been constructed in the area. The water used by the industrial plants is supplied from their own wells, that range in depth from 330 to 1,925 feet and average about 900 feet. In 1930 the average daily pumpage from the wells in this area was about 10 million gallons, and in 1941 the average daily pumpage was about 34 million gallons, or about 3½ times the pumpage in 1930.

Rice was formerly irrigated on a large scale near LaPorte in eastern Harris County, and near Webster in southern Harris County. However, only a few planters still operate in these areas, and only about 750 acres were planted in 1941.

The irrigation of rice in the Katy area was begun in 1902 with the planting of about 75 acres. Until about 1915 all of the water was supplied from wells less than 300 feet deep. In 1915 a well was drilled to a depth of about 500 feet and in 1922 another to about 800 feet. Since 1922 the average depth of the wells has been more than 500 feet. The number of wells drilled and the number of acres planted has increased greatly since 1902. In 1941 there were 95 wells irrigating 27,350 acres, in an area of about 300 square miles.

Geology and Its Relation to Occurrence of Ground Water

The Houston district, which lies within the West Gulf Coastal Plain, is divided physiographically into two parts by the Hockley Escarpment. This southeast-facing escarpment, which is the most prominent physiographic feature of the district, can be traced from Colorado County, north of Eagle Lake, through Austin County, central Waller County, northwestern Harris County, southern Montgomery County, and eastward into Louisiana. Barton[4] gives four possible explanations for the scarp but states that the available evidence indicates that it is a flexure scarp which has been buried to some extent by later alluvial deposits.

The area southeast of the scarp is a smooth, nearly featureless plain that rises from sea-level on the Gulf, to an altitude of about 165 feet, 80 miles inland, at the foot of the Hockley Escarpment, about 6 miles southeast of the town of Hockley. The average slope of the land surface is, therefore, about 2 feet to the mile. The surface of this relatively undisturbed depositional plain is broken only by the broad shallow valleys of the present streams and the remnants of older stream channels.

[4] Donald C. Barton, "Surface Geology of Coastal Southeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 10 (October, 1930), pp. 1302–03.

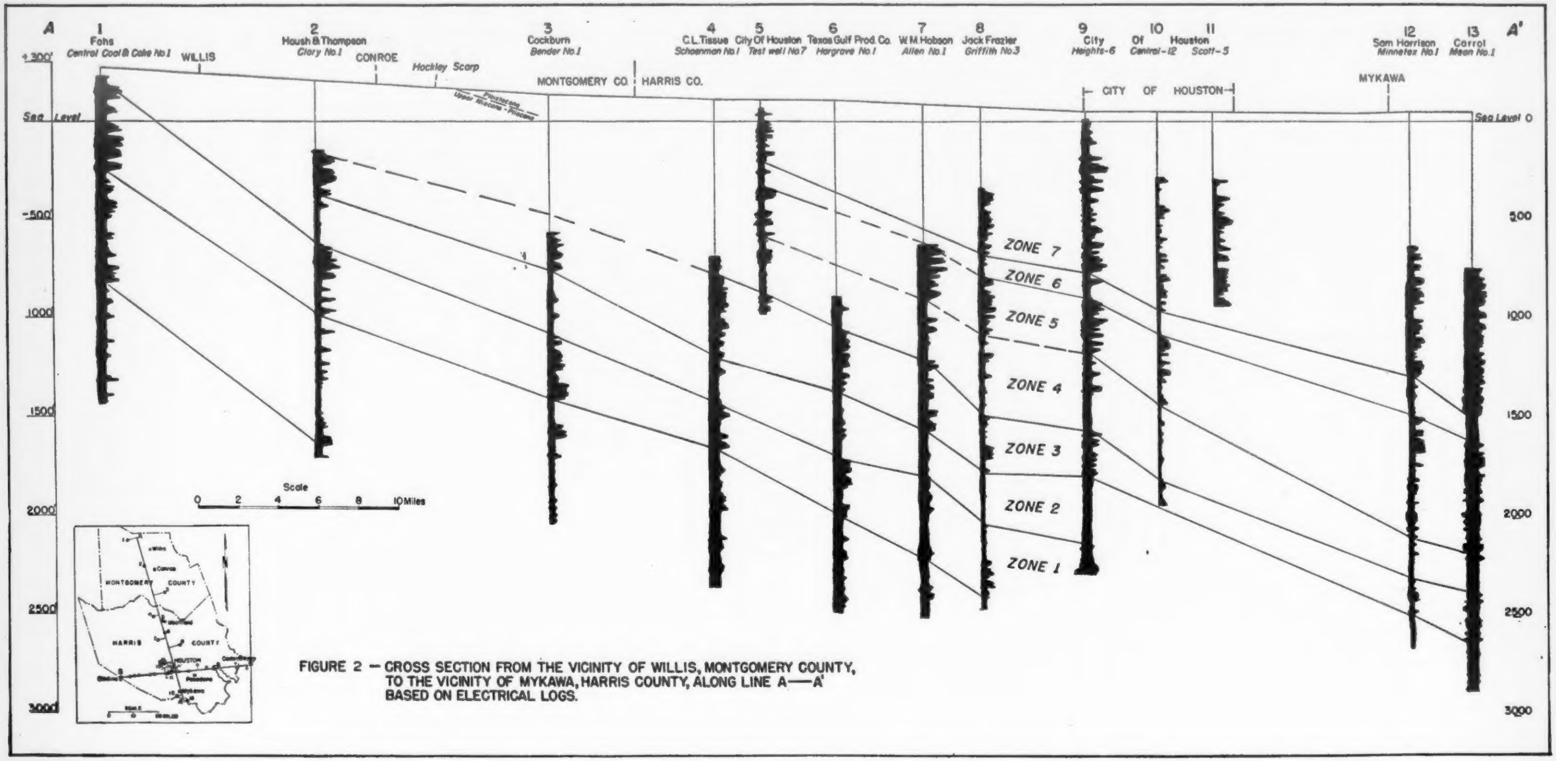

FIGURE 2 — CROSS SECTION FROM THE VICINITY OF WILLIS, MONTGOMERY COUNTY, TO THE VICINITY OF MYKAWA, HARRIS COUNTY, ALONG LINE A—A' BASED ON ELECTRICAL LOGS.

The area west and northwest of the scarp is a gently rolling plain dissected by many small streams, but erosion has not progressed far enough to obliterate the original surfaces of the formations.[5] The average slope of the land surface in this area is about 8 feet to the mile.

The major streams of the districts are San Jacinto River, Spring Creek, Cypress Creek, Buffalo Bayou, and Brays Bayou. The smaller streams generally carry water only during and after heavy rains. The tides reach inland from the Gulf to Houston through Galveston Bay and the Houston ship channel.

The geologic formations from which the Houston district obtains its ground-water supply are upper Miocene, Pliocene, and Pleistocene in age, and consist of permeable sand, gravel, and sandstone interbedded with relatively impervious clay. The formations dip southeastward, and thus successively younger formations crop out from northwest to southeast. Likewise, each formation is encountered at progressively greater depths toward the southeast (Fig. 2). The dip of the beds is extremely variable but in general increases with depth. The estimated dip of the older beds is about 50–60 feet to the mile, and of the younger beds about 20 feet to the mile, showing a thickening of the formations downdip.

The source of the sediments that make up the Miocene, Pliocene, and Pleistocene formations was largely the limestones and marls of the Cretaceous formations and sands, gravels, silts, and clays of the older Tertiary formations. Several species of redeposited Cretaceous fossils have been reported from the upper Miocene formations.[6] The clay sediments were derived principally from the Cretaceous rocks and the sand sediments were eroded mainly from the older Tertiary formations. The character of the sediments derived from these older formations depended on the rocks exposed throughout the drainage area of the streams, the stream profiles, and the depositional slopes.

A typical cycle in this process of sedimentation began with a gentle coastward tilting of the low flat plain which sloped gently toward the Gulf.[7] As the streams crossed the crest of the monocline their first action was to entrench themselves, gathering material from the monoclinal area. The smaller streams came together to form larger streams or rivers as they crossed the crest. As the streams reached the nearly featureless plain the channels could not accommodate the enlarged streams; therefore, the streams overflowed, and spread broadly and meandered widely over the plain, thus the velocity was decreased and a part of the load was depositied as alluvial fans. These fans eventually grew until they extended from one stream to the next to form a more or less continuous sheet of sediments. As the cycle progressed the streams eroded areas farther inland as well as older material in this plain. The material in this depositional plain was progressively

[5] John Doering, "Post-Fleming Surface Formations of Coastal Southeast Texas and South Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), p. 652.

[6] E. H. Sellards, W. S. Adkins and F. B. Plummer, "The Geology of Texas," *Univ. Texas Bull. 3232*, Pt. 3 (1932), p. 749.

[7] John Doering, *op. cit.*, p. 674.

transported and redeposited nearer the coast. Most of the sediments have been involved many times in this fluviatile transportation and redeposition.[8] A very flat alluvial plain bordering the coast was built as the finer material was deposited at the shoreline. As the streams reached this plain they became sluggish and their channels became clogged. Consequently, they continually shifted their courses and formed deltas. Eventually, a continuous alluvial plain was formed by the coalescing of the deltas.[9] Marine and lagoonal deposition, and wave and wind action were simultaneously in progress along the coastal fringe.

The formations resulting from this type of sedimentation consist of zones that are predominantly sand and zones that are predominantly clay. The "sand zones" are made up of extremely irregular and lenticular deposits of sand, gravel, silt, and clay. The sands are interbedded and intergraded with thin beds and layers of clay, sandy clay, and gravel. The interfingering layers and lenses grade into one another laterally and vertically in short distances. The thinner beds in many places change character or pinch out within a few hundred feet. The "clay zones" consist of mottled calcareous massive clay containing numerous calcareous nodules and interbedded with thin beds and lenses of fine- to medium-grained sand and sandstone. In general the clays are poorly stratified and are persistent only for short distances, although a few of the zones in which clay predominates can be traced throughout the district.

Although reports on the geology of the area have been written by several men[10] and the outcrop areas of the formations have been mapped,[11] there is very little definite information available on the subsurface correlation of the younger formations and on the relationship of these subsurface beds with the outcrop. Because most of the geologic studies in the area are directed toward the production of oil from deeper formations, relatively little attention has been given to these younger beds. The first 2,000 feet of beds drilled in the Gulf Coast are generally poorly logged, and cored or sampled sections are rare. The best data available for the study of these strata are furnished by electrical logs of oil tests and water wells. However, these data are limited because only a small percentage of the oil tests are electrically logged from the surface. Most of the electrical logs start at about 1,000 feet. If sufficient cored sections and electrical logs were avail-

[8] R. J. Metcalf, "Deposition of Lissie and Beaumont Formations of Gulf Coast of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 4 (April, 1940), p. 696.

[9] T. L. Bailey, "The Geology and Natural Resources of Colorado County," *Univ. Texas Bull. 2333* (1924), p. 96.

[10] Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water-Supply Paper 335* (1914), pp. 72–84.
T. L. Bailey, *op. cit.*, pp. 1–59.
Donald C. Barton, *op. cit.*, pp. 1301–22.
E. H. Sellards, W. S. Adkins and F. B. Plummer, *op. cit.*, pp. 727–61, 780–87.
John Doering, *op. cit.*, pp. 651–88.
Willis H. Meyer, "Stratigraphy and Historical Geology of Coastal Plain in Vicinity of Harris County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 2 (February, 1939), pp. 145–211.
R. J. Metcalf, *op. cit.*, pp. 693–700.

[11] "Geologic Map of Texas," *U. S. Geol. Survey* (1937).

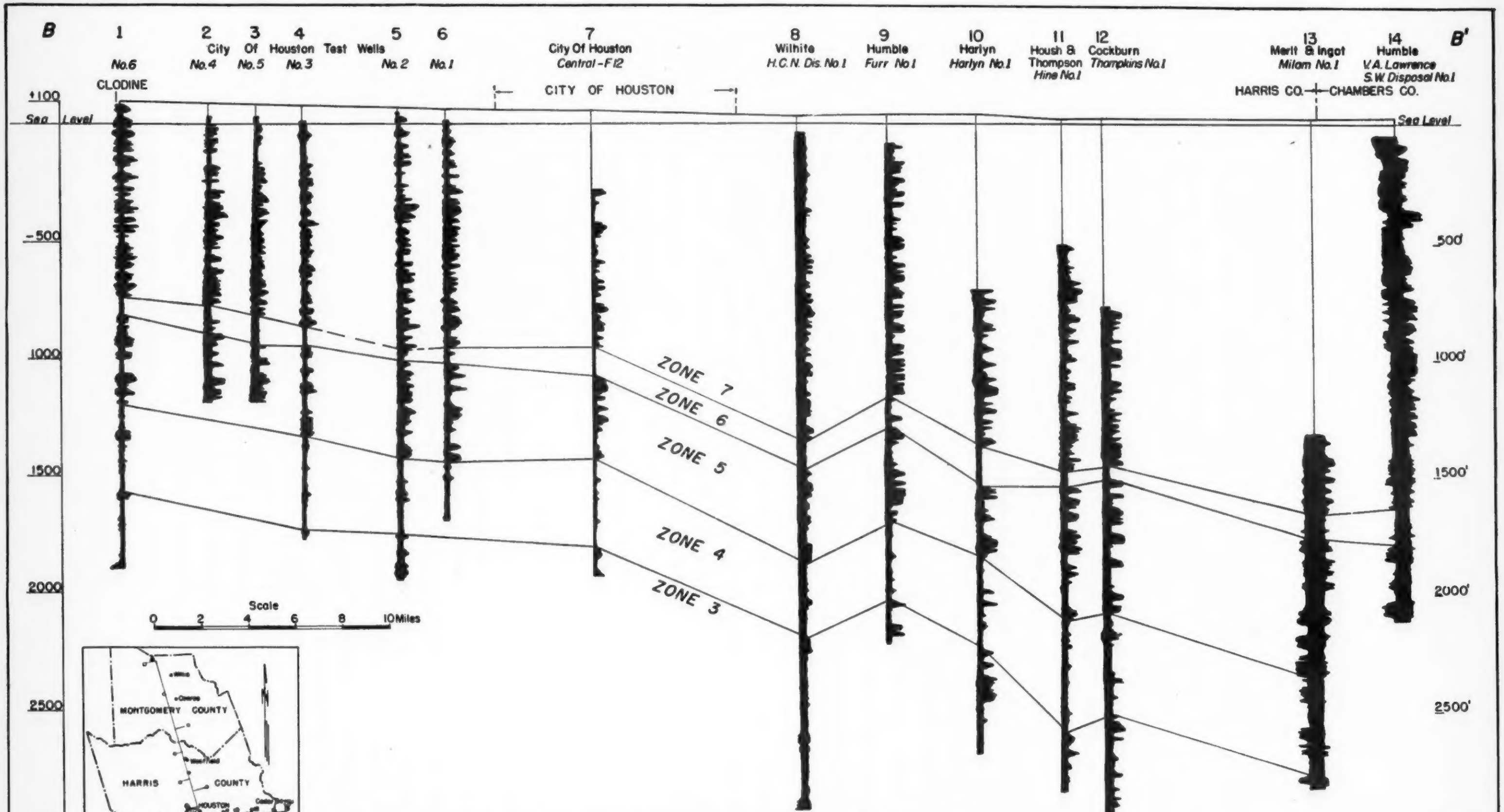

FIGURE-3 – CROSS SECTION FROM CLODINE, TO THE VICINITY OF CEDAR BAYOU, HARRIS COUNTY, ALONG LINE B—B' BASED ON ELECTRICAL LOGS.

able, these shallow strata probably could be correlated with surface formations. However, it is possible that some of the subsurface beds are not the equivalents of any outcropping beds.

In the present study it has been found possible to subdivide the upper Miocene, Pliocene, and Pleistocene section into seven zones. The separation of these zones is based on electrical logs of oil tests and water wells. No attempt has been made to correlate these zones with surface formations. However, the surface contact between the upper Miocene-Pliocene formations and the Pleistocene formations[12] is shown on the cross section in Figure 2. These zones have been correlated along two lines: line *AA′* (Fig. 2), extending from a point about 10 miles northwest of Willis, in northern Montgomery County, south through Houston to a point 3 miles southeast of Mykawa, in southern Harris County, and line *BB′* (Fig. 3), extending from the town of Clodine, on the Fort Bend and Harris County line, eastward through Houston to a point about $3\frac{1}{2}$ miles east of the Harris-Chambers County line. A brief description of the zones in the order of their deposition follows.

Zone 1 ranges from 240 to 440 feet in thickness and consists principally of beds of sand, although it contains some relatively thick beds and lenses of clay. The beds of sand yield water to wells in the Willis and Conroe areas in Montgomery County. Most of the wells in the Conroe area that derive water from this zone flow by artesian pressure. Three have a flow of about 100 gallons a minute. Another, about 4 miles north of the Montgomery-Harris County line has an estimated flow of about 200 gallons a minute and artesian pressure sufficient to raise the water more than 20 feet above the land surface. The water from these wells is low in mineral content and is suited for municipal and industrial purposes. Although the water from these sands in the Houston, Pasadena, and Katy areas is highly mineralized, it should be sufficiently low in mineral content 10 or 15 miles north of Houston to be of potential value as a supplementary source of ground water.

Zone 2 ranges from 220 to 320 feet in thickness and consists of clay, with lenses of sand, that is persistent throughout the district. In the Houston and Pasadena areas this relatively impermeable clay separates the highly mineralized water of zone 1 and the moderately mineralized water of zone 3, and acts as an effective barrier to the upward movement of the highly mineralized water.

Zone 3 ranges from 180 to 400 feet in thickness and consists of interfingering beds of sand and clay. In section *AA′* the zone is chiefly sand, but in section *BB′* it is composed largely of clay. Several wells in the Conroe area in Montgomery County draw from these sands. Well 5 in section *AA′* about 15 miles north of Houston yields water of low mineral content from the upper part of this zone. The artesian pressure in this well, when it was drilled in 1939, was sufficient to raise the water 27 feet above the ground surface. The sands in the upper part of this zone yield acceptable water to several wells in the Houston and Pasadena areas, but the sands in the lower part contain water too highly mineralized for

[12] "Geologic Map of Texas," *op. cit.*

most uses. All of the sands in this zone probably yield water of low mineral content a few miles north of Houston.

Zone 4 is a series of clay and sandy clay beds that contain numerous thin beds and lenses of sand. In many places the upper part of this zone grades into the overlying zone, making it difficult to differentiate the two. The thickness of this zone in section *AA′* ranges from 180 to 480 feet.

Zone 5 consists chiefly of thick beds of sand and lenses of clay. It ranges in thickness from 260 to 600 feet, thickening downdip. Many of the industrial and municipal wells in the Houston and Pasadena area and a few of the irrigation wells in the Katy area draw water from this zone. The yield of several of these wells ranges from 2,000 to 2,800 gallons a minute. The maximum specific capacity (gallons per minute per foot of drawdown) that has been computed is about 35. In the southern and extreme southeastern part of Harris County the water in these sands is highly mineralized.

Zone 6 is a series of clay beds ranging in thickness from 60 to 200 feet, and is continuous in most of the district. A few of the logs show a predominance of sand in this zone, but as a whole it is unimportant as a source of ground water. As it can be easily recognized in most of the electrical logs, it is an excellent key bed.

Zone 7 includes the most productive aquifers in the district. Its thickness ranges from a feather edge a few miles north of Westfield to about 1,700 feet in southern Harris County. It is composed chiefly of beds of fine- to coarse-grained sand but contains interbedded clay, silt, and gravel. Most of the wells in the district derive water from this zone. The maximum yield of municipal and industrial wells from this aquifer is about 2,200 gallons a minute and of irrigation wells about 3,500 gallons a minute. The highest specific capacity that has been reported is about 40. In general water from these sands is low in mineral content; however, in extreme southeastern Harris County the water in the lower part of this zone is highly mineralized.

Movement of Ground Water

The source of all of the water withdrawn from the wells in the Houston district is rainfall on the outcrop of the water-bearing sands northwest, north, and northeast of Houston. In general the rate of movement of the water through the sands is governed by Darcy's law, which states that the flow of water of given viscosity through a given cross-sectional area of sand of specific permeability is directly proportional to the hydraulic gradient of the piezometric surfaces.

Before there was any heavy pumping from the aquifers of the Houston district, the water moved from northwest to southeast, approximately in the direction of the dip of the water-bearing beds. A depression in the piezometric surface has been created by the withdrawals of water in the pumped areas, the shape and extent of which in January, 1942, is shown by means of contours in Figure 4. The water moves at right angles to the contours. Although water is moving into the Houston district from all directions, the map shows that most of it comes from the direction of the outcrop.

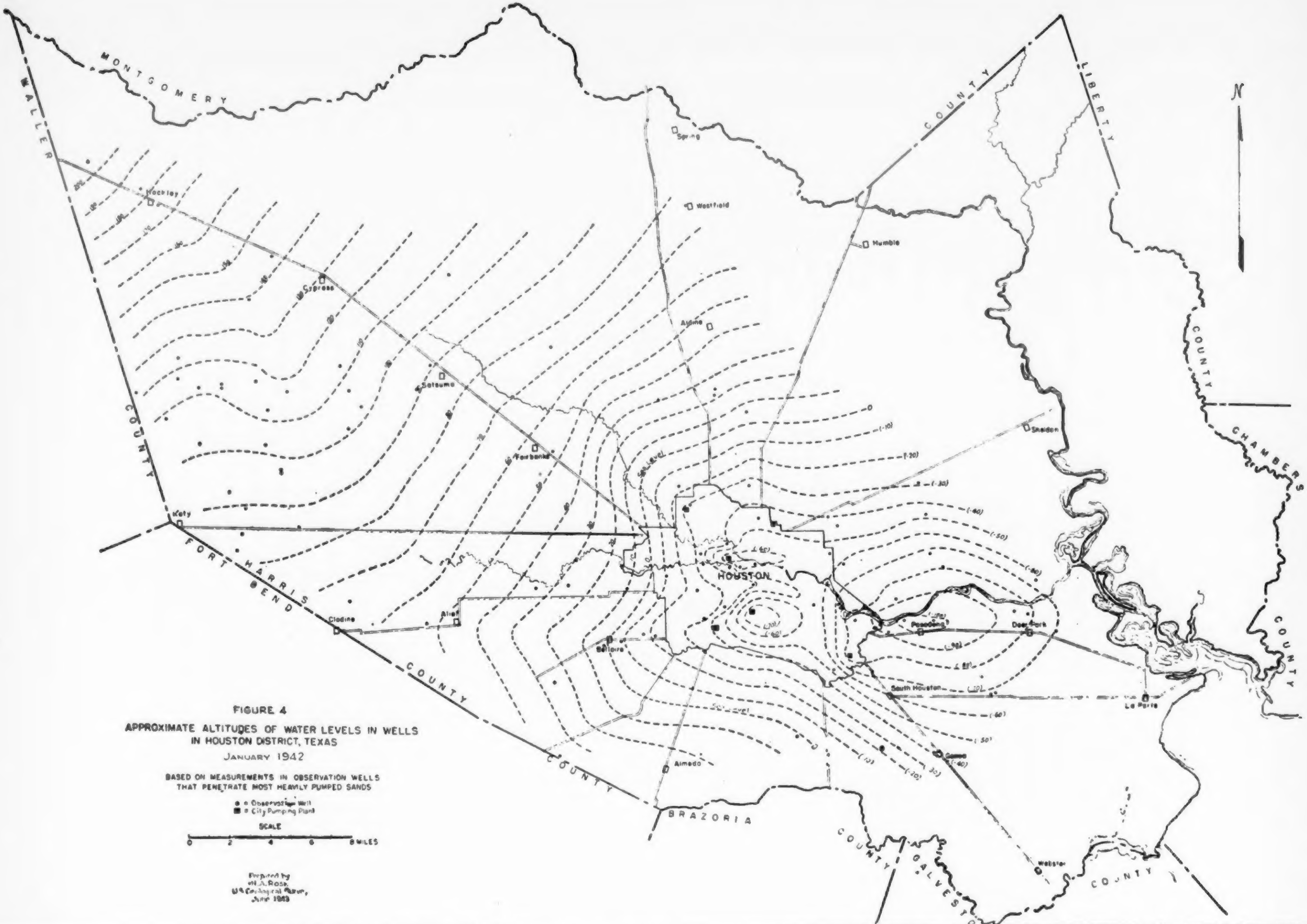

FIGURE 4

APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS IN HOUSTON DISTRICT, TEXAS

JANUARY 1942

BASED ON MEASUREMENTS IN OBSERVATION WELLS THAT PENETRATE MOST HEAVILY PUMPED SANDS

Prepared by
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U.S. Geological Survey,
June 1943

When pumping from a well in the Houston district is begun, the head of the water in the aquifer is immediately lowered in the vicinity of the well, and progressively as time goes on at greater distances from the well. The decline continues at a decreasing rate until the hydraulic gradient is established from the outcrop to the well so that all of the water pumped percolates from the outcrop.

In the early part of 1937, the piezometric surface in the Houston district was approximating equilibrium. The increases in the yearly rate of pumping which have occurred since then have caused a considerable net decline in the water levels. If the present rate of pumping is kept constant, the water levels probably will decline for a few more years, but at a decreasing rate, and will again approach equilibrium, but at stages considerably lower than those of 1937. If the rate of pumping is substantially decreased, the water levels will rise, but probably will not reach the altitudes at which they were for the same rate of pumping at an earlier time. Any increase over the present rate of pumping will increase the rate of decline of the water levels and will postpone the time when equilibrium may be reached.

In the fall of 1939 a series of pumping tests were made on the Houston municipal wells. The results of these tests were analyzed by Jacob[13] by means of the non-equilibrium formula[14] and the coefficients of permeability and storage were computed. The coefficients obtained from these tests varied over wide range, partly because of the imperfect conditions under which the tests were made, but principally because of the variations in thickness and character of the water-bearing sands and their associated clays. The practical application of these coefficients has been discussed by Guyton in another paper.[15]

Theoretically the non-equilibrium formula can be used with the coefficients to compute future declines of water levels that will result from an increase in the rate of pumping. However, the non-equilibrium formula is based on the assumptions that the aquifer is of uniform thickness and infinite in extent, that the beds above and below are completely impermeable, and that when the artesian head is lowered within the aquifer water is given up instantaneously from storage. The aquifer from which the Houston district obtains its ground water is made up of about 600 feet of sand consisting of many beds that vary widely in thickness, extent, and permeability, interbedded with layers and lenses of relatively impermeable clay. As shown in Figure 5, the thickness of sand in wells a few hundred feet apart may be greatly different, and the degree of interconnection between the beds may be extremely variable. Because of the wide variation of the geologic conditions the formula is not considered applicable to the Houston district as a whole. Estimates of future declines in water levels that will be caused by present

[13] C. E. Jacob, "Coefficients of Storage and Transmissibility Obtained from Pumping Tests in the Houston District, Texas," *Trans. Amer. Geophys. Union* (1941), pp. 744–56.

[14] C. V. Theis, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *ibid.* (1935), pp. 519–24.

[15] W. F. Guyton, "Application of Coefficients of Transmissibility and Storage to Regional Problems in the Houston District, Texas," *ibid.* (1941), pp. 756–70.

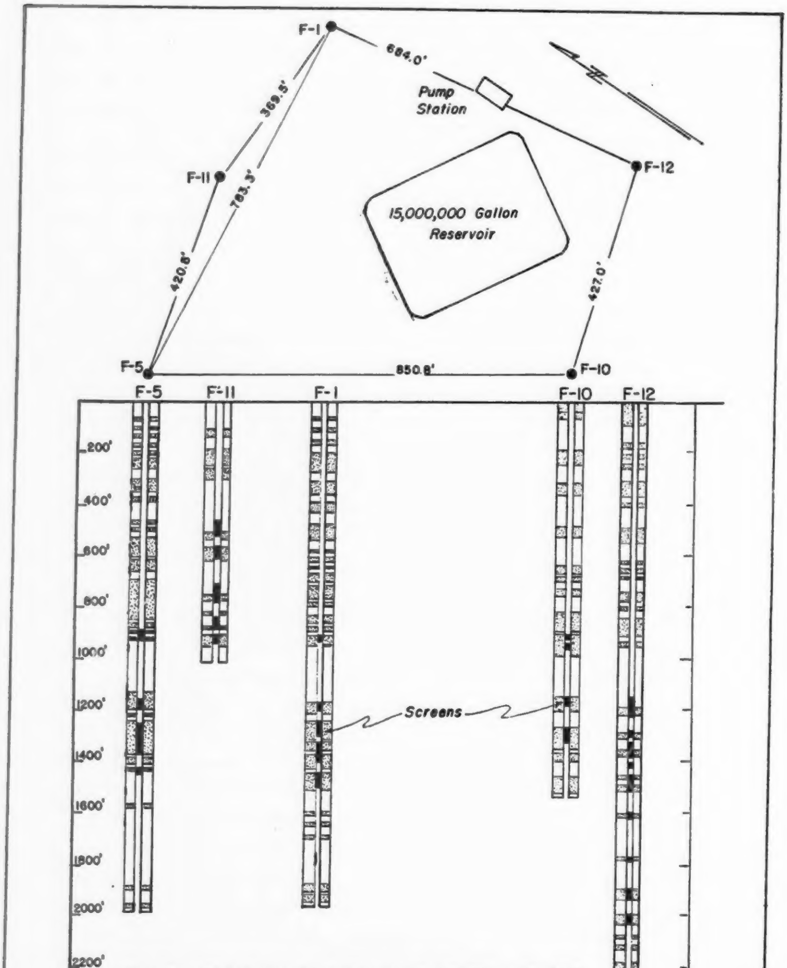


FIG. 5—LOCATION OF WELLS AT CENTRAL PLANT, HOUSTON, TEXAS, AND COLUMNAR SECTIONS SHOWING SANDS BASED ON WELL-LOGS.

increased rates of pumping must still be based largely on long-term records of water levels with records of the rates of pumping.

Even though the non-equilibrium formula is not considered reliable in predicting future declines in water levels that will be caused by present and increased rates of pumping in the Houston district much valuable information has been

obtained by its application. Guyton,[16] by using average values of the coefficients of permeability and storage obtained from the pumping tests, computed the rate of inflow and the amount of water taken from artesian storage in the Houston and Pasadena areas. Although admittedly rough, the computations show that withdrawal of water from storage in the heavily pumped areas is relatively small in comparison to the total amount pumped. The non-equilibrium formula also has been applied in making estimates of the relative merits of various groups of wells and locations of new wells with hypothetical changes in the rate of pumping.[17] This was done in connection with the contemplated installation of new wells at considerable distances from the present center of pumping. This type of information serves a very important function in any ground-water investigation. However, the results of such theoretical applications must be carefully interpreted in the light of the existing geologic conditions and the limitations of the methods.

Pumpage and Water Levels

HOUSTON AND PASADENA AREAS

PUMPAGE

Nearly all the water pumped in the Houston and Pasadena areas comes from approximately 255 wells. The estimated average quantities of water pumped in the Houston and Pasadena areas in 1930, 1935, 1937, 1939, 1940, and 1941 are given in Table I.

TABLE I

Estimated Average Daily Pumpage in Houston and Pasadena Areas
(Millions of gallons a day)

	1930	*1935*	*1937*	*1939*	*1940*	*1941*
Houston Water Department (from city records)	25.8	24.5	25.2	27.2	28.8	27.2
Houston independent public water supplies and industrial wells	14	14	16	16	17	16
Pasadena industrial wells	10	10	29	29	32	34
Total in Houston and Pasadena areas	50	49	70	72	78	77

In 1930 the average rate of ground-water withdrawal in the Houston and Pasadena areas was about 50 million gallons a day. From 1930 to 1936 the rate of pumping was more or less constant. In March, 1937, the Champion Paper and Fibre Company began operating a group of new wells near Pasadena and the pumpage from these wells during the remainder of the year averaged about 19 million gallons a day. This represented an increase of about 40 per cent over the average daily pumpage in 1936. In 1938 the average daily pumpage from these wells decreased to about 16 million gallons. There was no material change in the rate of withdrawal from other wells in the Houston and Pasadena areas in 1937 and 1938. In the fall of 1939 and the spring and summer of 1940 the demands by

[16] *Ibid.*, p. 767.

[17] *Ibid.*, p. 768.

industries and muncipalities increased materially, and the average daily pumpage was increased to 72 million gallons in 1939, and 78 million gallons in 1940. The average daily pumpage in 1941 was about 77 million gallons, or about 1 million gallons less than in 1940.

The average daily consumption for public supply in 1941 was about 2 million gallons less than in 1940, although the number of consumers increased during the year. This decrease was apparently due to the unusually heavy rainfall and frequency of showers during the summer. The average daily consumption by industries in 1941 was about 2 million gallons more than in 1940.

The Water Department of the City of Houston owns and operates 23 wells in seven widely spaced areas within the city. Most of the suburban communities obtain public supplies from their own wells, and industrial requirements are met in large part from privately owned wells. Table II gives the estimated average daily pumpage during 1941 for public and industrial use. The subdivisions show the pumpage by the Houston Water Department, the independent public water supply agencies, and the nine types of industries using the most water.

TABLE II

ESTIMATED PUMPAGE FOR PUBLIC AND INDUSTRIAL SUPPLIES IN HOUSTON AND PASADENA AREAS IN 1941

	Number of Plants	*Number of Wells*	*Average Pumpage (Millions of Gallons a Day)*
Houston Water Department	7	23	27.2
Paper mill	1	9	21.0
Oil refineries	6	21	11.8
Railroads	10	21	3.0
Ice plants	18	24	3.0
Independent public-water supplies	20	33	2.3
Office buildings, hotels, and theaters	26	29	1.7
Tool companies	2	3	1.2
Packing companies	3	6	1.3
Laundries	13	13	0.9
Light and power plants	2	5	0.8
Miscellaneous industrial plants using more than 5,000 gallons a day	57	68	2.9
Total	165	255	77.1

Table II shows that 53 of the 255 wells produce 60 million of the 77 million gallons of water consumed daily.

WATER LEVELS

In 1908 most of the wells in the Houston and Pasadena areas flowed by artesian pressure.[18] The maximum artesian pressure recorded in these areas was sufficient to raise the water about 20 feet above the land surface. There was considerable decline in head from 1908 to 1920, and from 1920 to 1931 the decline averaged about 4 feet a year. The water levels in 1931 were between 50 and 80 feet below the surface. From 1931 to 1937 the water levels in the two areas re-

[18] Alexander Deussen, *op. cit.*, pp. 225–28.

mained practically constant, but the large increase in the rate of pumping in the spring of 1937 caused a marked decline (Figs. 6 and 7). The water levels began to decline almost immediately in observation wells near Pasadena. In more distant wells the levels declined less promptly and less rapidly. In some wells in

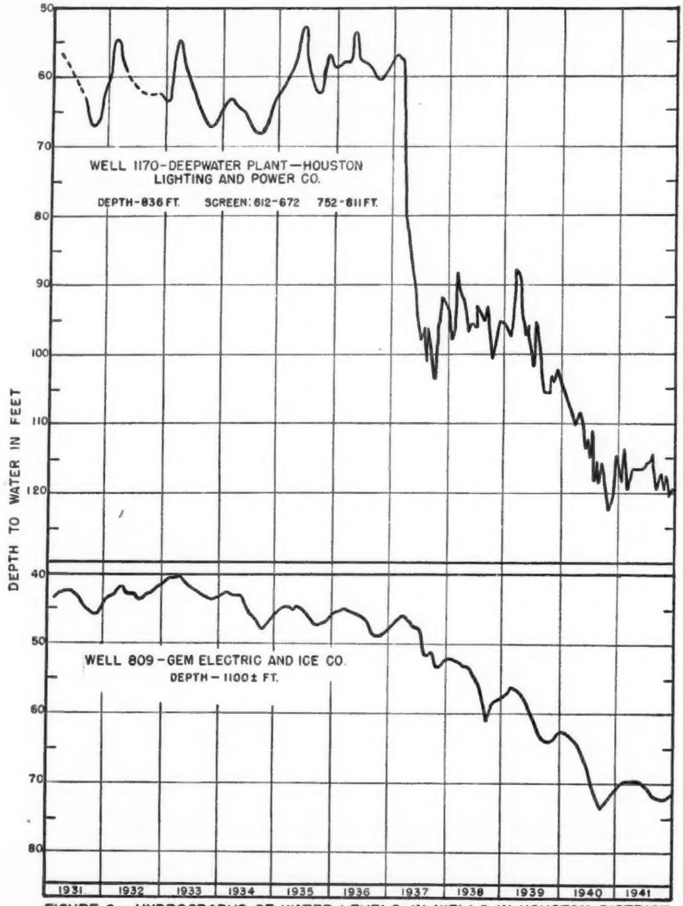


FIGURE 6 — HYDROGRAPHS OF WATER LEVELS IN WELLS IN HOUSTON DISTRICT

the central and western parts of Houston several months elapsed before the decline resulting from this new pumpage was noticeable. From the latter part of 1937 to the corresponding period in 1938 the water levels in wells in the Pasadena area remained constant or rose slightly due to a decrease in local pumping, whereas, the water levels in wells in the Houston area continued to decline during 1938

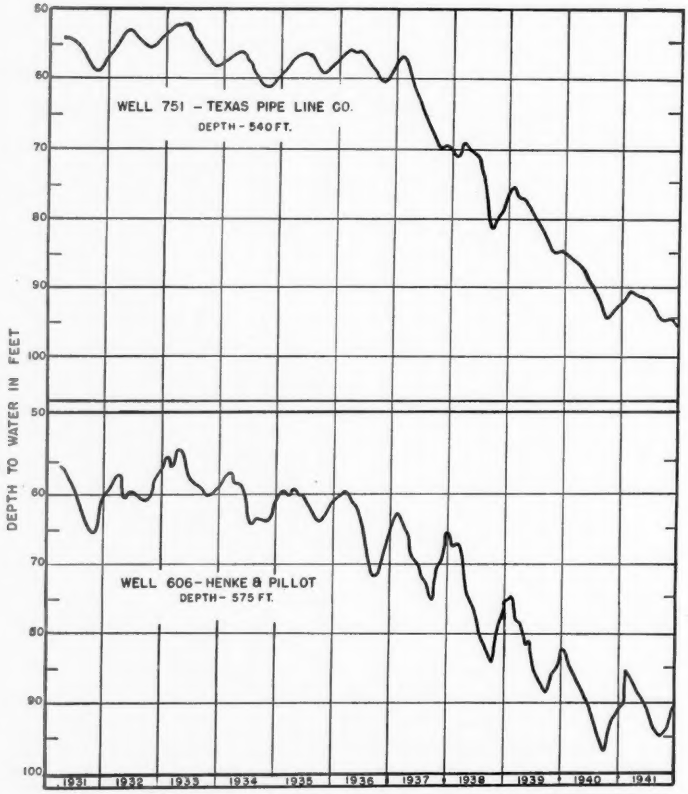


FIGURE 7 — HYDROGRAPHS OF WATER LEVELS IN WELLS IN HOUSTON DISTRICT

and in some wells the decline was greater than in 1937. During 1939 and 1940 the rate of pumping in the Pasadena and Houston area was again increased and the

TABLE III

DECLINE OF WATER LEVELS IN SELECTED OBSERVATION WELLS IN HOUSTON DISTRICT BETWEEN 1937 AND 1942, BASED ON HIGHEST OBSERVED SPRING LEVELS

Well No.	*Distance from Pasadena (Miles)*	*Depth (Feet)*	*1937–38*	*1938–39*	*1939–40*	*1940–41*	*1941–42*	*1937–42*
1170	2 W.	836	31	—[a]	19.5	6.5	4.5	61
1302	6½ S.	832	18	4.5	4.8	7.5	4.0	49
751	7 NW.	540	12.6	6.6	9.9	6.2	2.9	38.2
656	11½ NW.	665	10.8	6.1	10.1	3.9	1.5	32.4
619	10½ W.	625	2.2	8.7	7.5	4.0	4.0	26.4
602	13½ W.	1,038	7.7	5.8	6.2	4.6	1.4	25.7
809	16 W.	1,100±	6.4	3.9	6.6	7.1	0.6	24.6
264	21 NW.	900±	11.8	2.5	2.9	0.1	—[b]	15.8

[a] Rose 0.5 foot.
[b] Rose 1.5 feet.

water levels in wells in both areas declined rapidly and persistently. Since 1940 the decline has continued but at a decreasing rate.

The decline of water levels between 1937 and 1942 in eight selected observation wells in the Houston and Pasadena areas, based on the highest observed levels between January and May of each year, is shown in Table III.

KATY RICE-GROWING AREA

PUMPAGE

All the water used for the irrigation of rice in the Katy area is supplied from wells. These wells range in depth from about 150 to 1,100 feet, and average more than 500 feet. The wells are provided with 16- to 24-inch pump pits and 8- to 12-inch casing and screen. The screens, which in most of the wells consist of slotted casing, are set opposite all of the water-bearing beds. Nearly all of the wells are gravel walled. The pumps are of the deep-well turbine type and are driven by electric or diesel motors.

TABLE IV

PUMPAGE AND RAINFALL IN KATY RICE-GROWING AREA

	1930	*1935*	*1937*	*1938*	*1939*	*1940*	*1941*
Number of wells	45	40	61	71	78	88	95
Number of acres irrigated	9,400	8,000	13,750	16,370	19,950	24,200	27,350
Amount of water pumped, in acre-feet[a]	20,200	15,700	33,600	28,000	44,900	50,400	25,800
Average amount of water pumped, in millions of gallons a day throughout year	18	14	30	25	40	45	23
Average amount of water pumped, in millions of gallons a day during pumping season	58	50	105	130	136	166	170
Amount of water pumped in acre-feet per acre	2.2	1.9	2.5	1.7	2.2	2.1	0.9
Rainfall, in acre-feet per acre (May to September)[b]	0.9	1.9	0.9	1.9	1.6	1.4	2.6
Total amount of water applied to land (irrigation+rainfall), in acre-feet per acre	3.1	3.8	3.4	3.6	3.8	3.5	3.5

[a] One acre-foot equals approximately 326,000 gallons.
[b] Average of rainfall recorded by U. S. Weather Bureau at Hempstead, Houston, Sealy, and Sugarland. No record for Hempstead in 1938 or for Sealy in 1939.

The wells are pumped only during the rice-growing season, which begins about the first of May and lasts about 130 days. The number of days of pumping varies from season to season, but the average is about 100 days each year.

Table IV shows the number of wells used for the irrigation of rice in the area; the number of acres irrigated; the total amount of water pumped, in acre feet, in millions of gallons a day throughout the year, and in millions of gallons a day during the pumping season; and the average amount of water, including rainfall, applied to an acre of land in the seasons of 1930, 1935, 1937, 1938, 1939, 1940, and 1941. The pumpage shown in the table was computed from records of the American Rice Growers Coöperative Association, the Houston Lighting and Power Company, and measurements of discharge of water from the individual wells.

The total amount of water applied per acre (including rainfall), was remarkably uniform throughout the 7 years for which data are available. Although there has been an annual increase in the acreage irrigated since 1935, the amount of water pumped in the 1938 growing season was less than in the season of 1937, and less in 1941 than in 1940. The decreases in pumpage in these years were due to abnormally heavy rainfall. The total amount of water applied per acre to the land during the pumping seasons of the 2 years was about the same as in other years.

WATER LEVELS

Available records show that none of the irrigation wells ever had an artesian flow; the water levels in them as early as 1903 were more than 30 feet below the surface. According to John Cope, a rice grower in the area, the water levels declined only about 5 feet between 1903 and 1931. Fluctuations of water levels as shown by March measurements in observation wells since 1931 are as follows.

1931 to 1939, an average decline of 5.9 feet
1939 to 1940, an average decline of 2.6 feet
1940 to 1941, an average decline of 1.6 feet
1941 to 1942, an average rise of 2.1 feet

Thus the total decline from 1931 to 1942 averaged about 8.0 feet. The rise in water levels between March, 1941, and March, 1942, was due to: (1) a decrease in the rate of pumping, the pumpage in 1941 being about half as much as it was in 1940, (2) greater distribution of pumping because of a wider spacing of new wells, and (3) increased recharge resulting from the unusually heavy rainfall in 1941.

Chemical Character of Ground Water

Several hundred analyses of samples of water from wells in the district show that in general the quality of the ground water used in the Houston district compares favorably with other public, industrial, and irrigation supplies in the United States. The quality of the water at different depths in the Houston area, as shown by analyses of water from six selected wells, is given in Table V.

In general the mineral content of the ground water increases with depth; therefore, it determines the maximum depths to which wells are drilled in the district. The higher mineral content of the water from the deep sands is due largely to increased amount of sodium chloride. According to analyses of samples of water from wells and drill-stem tests in exploration holes, water of low chloride content can be obtained at a depth of about 2,000 feet at Houston, about 1,900 feet at Pasadena, 2,000 feet in test well 2 on the Houston-Clodine road, 1,850 feet in test well 8 near South Houston, and 1,600 feet in test well 6 at Clodine. On the other hand, samples of water having sufficient chloride content to be objectionable for public use have been obtained from sands at about 2,100 feet at Houston, 2,000 feet in test well 6 at Clodine, about 1,000 feet at Baytown, and about 1,000 feet near Webster. The electrical logs of oil tests and water wells indicate that water of low mineral content occurs down to depths as great as 2,000 to 2,100 feet in Houston and to even greater depths in the area north of Houston,

TABLE V

ANALYSES OF WATER FROM SELECTED WELLS IN HOUSTON AREA
(Parts per million)

Well number	693	656	907	732	736	535
Owner	First Nat'l. Bank Bldg.	Texas Creosoting Co.	Garden Villas	Gould's Laundry	Houston Packing Co.	R. H. Goodrich
Depth of well (feet)	363	666	897	1,391	1,618	1,996
Calcium (Ca)	48	39	—	—	—	3.6
Magnesium (Mg)	13	10	—	—	—	4.6
Sodium and Potassium (Na+K)	49	45	—	—	—	229
Bicarbonate (HCO_3)	258	220	253	346	420	451
Sulphate (SO_4)	17	15	20	2	2	2
Chloride (Cl)	36	28	38	50	74	106
Total dissolved solids	290	245	299	371	471	569
Total hardness as $CaCO_3$	173	138	40	44	34	28
Date of collection	1-30-42	1-28-42	8-8-39	1-30-42	1-20-42	10-14-41
Analyst	W. W. Hastings	W. W. Hastings	E. W. Lohr	W. W. Hastings	W. W. Hastings	W. W. Hastings

Water in wells 693 and 656 is calcium bicarbonate type and the water from wells 907, 732, 736, and 535 is sodium bicarbonate type.

but that south and southeast the depths to which water of low mineral content occurs become progressively less. The approximate depths at which water of relatively high mineral content should be encountered, as indicated by electrical logs, are shown in Figure 8.

Since 1931 samples of water collected periodically from about 60 selected widely spaced wells in the district have been analyzed primarily to determine if

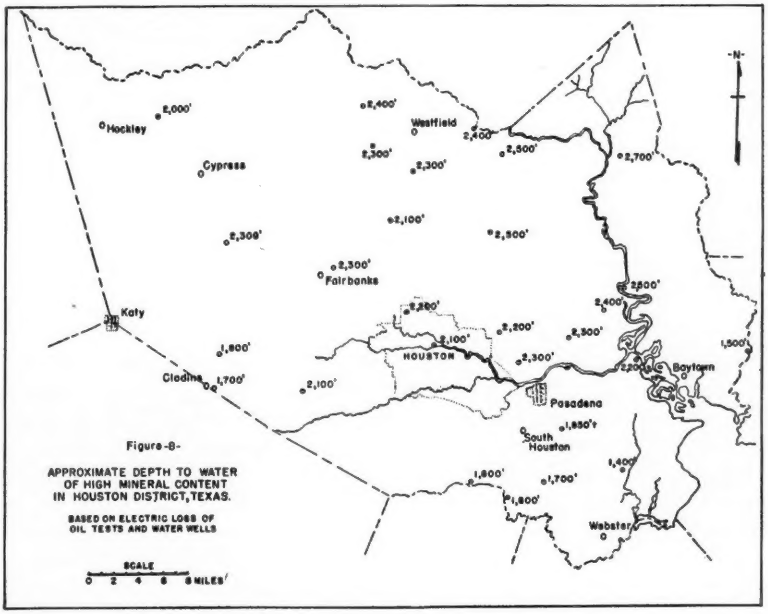


Figure-8-
APPROXIMATE DEPTH TO WATER OF HIGH MINERAL CONTENT IN HOUSTON DISTRICT, TEXAS.
BASED ON ELECTRIC LOGS OF OIL TESTS AND WATER WELLS

the chloride content has increased. According to these analyses, including the latest, January, 1942, there has been no change in the mineral content of the ground water in the formations from which the Houston district obtains its supply.

RESULTS OF EXPLORATORY WELL DRILLING

In conjunction with the ground-water investigation, a program of exploratory drilling by the City of Houston was started in March, 1939, and completed in August, 1939. Altogether, 13 deep test wells were drilled, of which 9 are west of Houston along the Houston-Clodine road; 2 about 15 miles north of the city limits at Westfield; and 2 southeast of the city on the South Houston-Laporte highway, about 3 miles east of the town of South Houston (Fig. 1).

The drilling program had three main objectives, as follows: (1) west of Houston, to determine the thickness and character of the water-bearing sands, the chemical character of the water in them, and the artesian pressures to a maximum depth of 2,000 feet; (2) north of Houston, to determine the artesian pressures and to obtain observation wells, both in the sands at moderate depth, which are correlative with the heavily pumped sands at Houston, and in the deeper sands, which are undeveloped or lightly drawn upon; and to determine the quality of the water; (3) southeast of Houston, to determine the artesian pressures in the fresh water-bearing sands and the position and thickness of sands containing brackish or salty water; and by using the test holes as observation wells to obtain advance information if there should be encroachment of salt water from the direction of the Gulf.

Regarding ground-water conditions in the localities explored, the following conclusions are drawn. Water-bearing sands having an average thickness of 600 feet occur between the surface and a depth of 1,500 feet along the line of test wells from the western city limits of Houston to Clodine. A supply of water is available north of Houston in deep sands that are practically untouched by existing wells. The water contained in these sands is suitable for domestic and industrial purposes. The occurrence of fresh water in the deep sands in the vicinity of South Houston indicates that salt-water encroachment from down the dip through the sands tapped by wells in the heavily pumped area is not likely to occur for at least many years.

SUMMARY

The geologic formations from which the Houston district obtains its water supply are upper Miocene, Pliocene, and Pleistocene in age. The formations dip southeastward; hence, successively younger formations crop out from northwest to southeast. These formations were deposited during several cycles of continental deposition and are for the most part fluviatile, deltaic, and lagoonal in origin. The formations consist of zones that are predominantly sand and zones that are predominantly clay. The "sand zones" are made up of extremely irregular and lenticular deposits of sand, gravel, silt, and clay. The sands are interbedded and intergraded with thin beds and layers of clay, sandy clay, and gravel. The "clay zones"

consist of mottled calcareous clay containing thin beds and lenses of sand. A few of the zones in which clay predominates can be traced throughout the district. In the present study the section has been subdivided into seven zones. The separation of these zones is based chiefly on electrical logs. Most of the wells in the district draw water from zones 5 and 7.

The annual pumpage in the Houston and Pasadena areas was nearly constant from 1930 to 1936, inclusive, but increased about 60 per cent between 1937 and 1941. From 1930 to 1936 the water levels in the Houston and Pasadena areas were in approximate equilibrium. The large increase in the rate of pumping in 1937 caused a marked decline in the water levels, and additional increases in pumpage in 1939 and 1940 caused further decline. Although the pumpage was decreased slightly in 1941 the decline continued but at a decreased rate.

In the Katy area the annual pumpage decreased somewhat from 1930 to 1935, but increased more than three-fold from 1935 to 1940. The annual pumpage was, however, only about half as much in 1941 as in 1940. There has been a net decline in water levels for several years, although the amount is only a fraction of the decline in the Houston and Pasadena areas. However, in 1941 there was a general rise in the water levels.

If the present rate of pumping in the district remains constant the water levels will probably continue to decline for a few years longer, but at a decreasing rate, and will gradually approximate equilibrium. Any increase over the present rate of pumping will accelerate the decline, whereas a decrease of considerable magnitude will cause a rise. Correlation between past water levels and rates of pumping gives a reliable basis for predicting future fluctuations in the water levels in the district.

The quality of the ground water used in the district compares favorably with other public, industrial, and irrigation supplies in the United States. Analyses of water samples taken periodically since 1931 show no change in the mineral content of the ground water in the district.

Data obtained from a program of exploratory drilling show that an additional supply of ground water is available west and north of Houston, and that the occurrence of fresh water in the deep sands near South Houston indicates that salt-water encroachment from down the dip is not likely to occur for at least many years.

ACKNOWLEDGMENTS

Grateful acknowledgment is expressed to the persons who contributed information and assisted in the preparation of this report. W. F. Guyton worked with the writer in the collection, compilation, and interpretation of the data, and several of the members of the Geological Survey reviewed the manuscript and offered valuable suggestions and criticisms. T. L. Bailey of the Shell Oil Company and Carl B. Richardson of the Barnsdall Oil Company read the geologic section and offered helpful suggestions. The City of Houston and the oil companies having wells in the district made electrical logs available for study and publication.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 8 (AUGUST, 1943), PP. 1102-1122, 8 FIGS.

SUBSURFACE STUDY OF JENNINGS FIELD, ACADIA PARISH, LOUISIANA[1]

C. B. ROACH[2]
Lake Charles, Louisiana

ABSTRACT

The Jennings field is on a piercement-type salt plug, where shallow supercap production from upper Miocene sands was discovered in August, 1901. Flank production from Oligocene *Marginulina*-Frio sands was first obtained in 1929, but active development of the sands did not begin until 1936. The *Marginulina*-Frio sands are broken into many small blocks by faulting of Oligocene and post-Oligocene age. The Oligocene faulting occurred with few exceptions just after the beginning of *Heterostegina* time and it is buried under an unconformity near the base of the *Heterostegina* sediments. Later movements of the salt during the deposition of the Oligocene and Miocene sediments caused additional unconformities and thinning of the strata toward the salt plug.

At present the salt plug has penetrated as far as the middle Miocene and is surmounted by thick cap rock which is in contact on the east half of the dome with a mineralized sand section in the Miocene. This mineralization is of major importance, and its origin and mechanics are discussed in some detail. It was formed during a period of seeming quiescence on the part of the salt, and, when upward movement was resumed, the salt was unable to break the bond between the cap rock and the mineralized sand. As a result the salt took the path of least resistance and bulged outward on the west flank where the associated sand beds are not so highly cemented. This suggests the manner in which salt spines and offset salt plugs originate.

It is concluded that the salt bulge broke the continuity of the west flank sediments in fairly recent time and allowed the oil accumulations on that side of the field to migrate to the supercap sands.

INTRODUCTION

The Jennings field is situated in Acadia Parish, Louisiana, in T. 9 S., R. 2 W., and lies midway between Houston, Texas, and New Orleans, Louisiana. It is a piercement type of salt dome in which the salt core rises to a height of approximately 2,500 feet subsea and is surmounted by a thick cap.

The first well, which was drilled by the Heywood Brothers of Beaumont for the Jennings Oil Company,[3] was located on the evidence of gas seepages and a topographic "high." The well blew out in August, 1901, from a shallow sand at the depth of 1,882 feet, only 8 months after the discovery of the Spindletop field in Texas.

The first Oligocene flank production was discovered in 1929 by Yount-Lee in a well on the Houssiere-Latrielle lease on the east flank, but the extent of the accumulation was not realized until the Shell Oil Company completed Conover Community No. 1 on the southeast flank on June 25, 1936, at the total depth of 7,545 feet. Development then proceeded rapidly and 120 wells have now been drilled to the *Marginulina*-Frio sand series.

The Jennings field is one of the major oil fields in the Louisiana Gulf Coast. The estimated ultimate recovery for the entire field is approximately 120,000,000

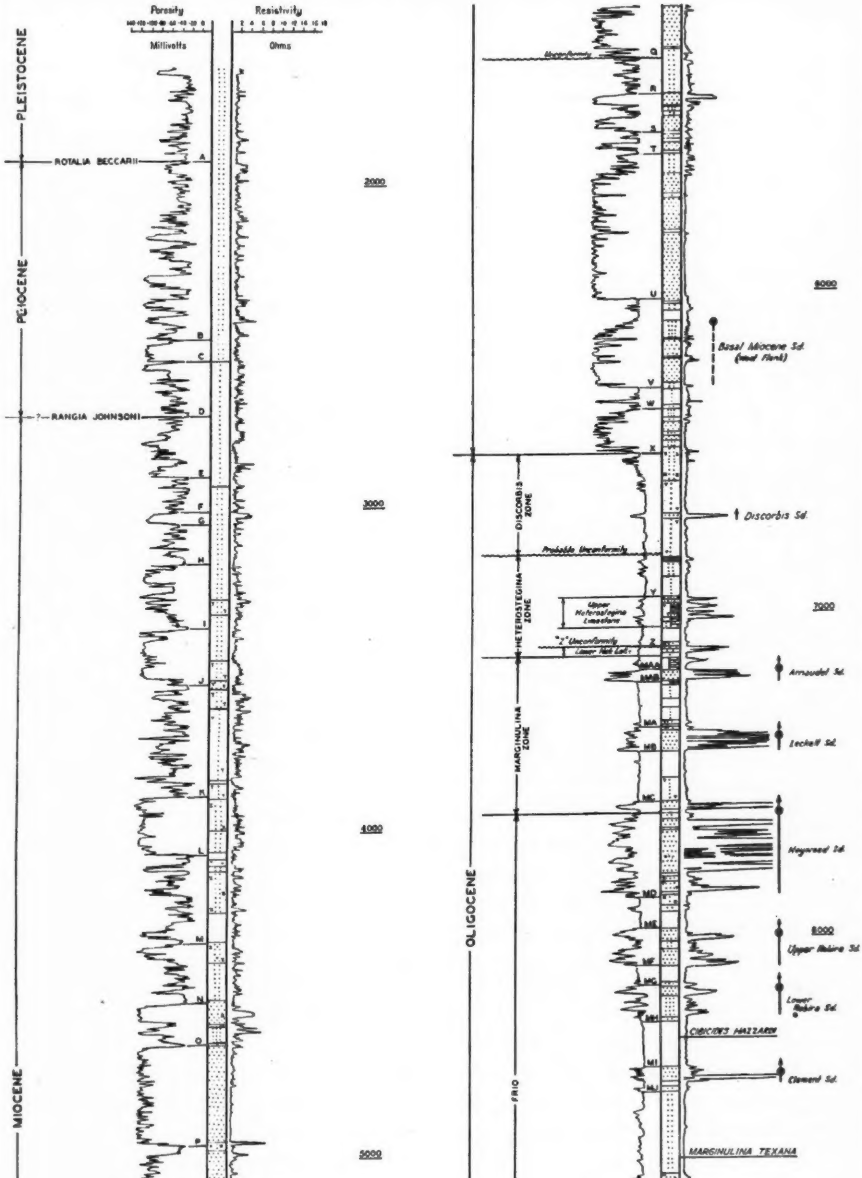
[1] Revised version received, April 19, 1943. Original paper presented before the Association at Houston, April 2, 1941. Published with special permission of the Shell Oil Company, Incorporated, Houston, Texas.

[2] Division subsurface engineer.

[3] Donald C. Barton and R. H. Goodrich, "The Jennings Oil Field, Acadia Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 1 (January, 1926), pp. 72–92.

FIGURE 1

TYPE LOG
JENNINGS DISTRICT
ACADIA PARISH, LA.



barrels, of which about 50 per cent will be produced from the flank Oligocene sediments and 50 per cent from the supercap sands. The total production to the end of 1941 was 77,000,000 barrels.

STRATIGRAPHY

The sediments so far penetrated on the flanks of the Jennings dome range in age from Pleistocene to Oligocene. A type log compiled from the electric logs of several wells on the southwest and south flanks is shown in Figure 1. The system of letters used to designate the stratigraphic markers is arbitrary and of strictly local application, and has no connection with the general stratigraphic column in this region. No attempt has been made to differentiate between the various formations of the Miocene-Pleistocene section, which have been described in detail by M. T. Halbouty.[4]

Only a few electrical logs of the shallow supercap wells are available, and, although with one or two exceptions electrical surveys have been made of all the flank wells, they have rarely been made before cementing the surface casing at approximately 1,500 to 1,700 feet. Very little is known, therefore, about the shallow formations or the structure of the supercap beds, and the type log (Fig. 1) begins with the top of the first electrical survey in a typical flank well.

The top of the Pliocene appears to correspond with marker *A* on the type log at which point *Rotalia beccarii* was observed. The top of the Miocene, based on the first occurrence of *Rangia Johnsoni*, is at marker *D*. From markers *A* to *N* the strata consist mainly of interbedded sands and shales with a few thick sand beds, but from markers *N* to *X* the formations are predominantly sand broken by well defined shale beds. This lower Miocene section shows the effect of a series of salt movements, one of which resulted in a pronounced unconformity at marker *Q*. This break is readily observed on radial sections and appears to be developed all around the dome. The other movements were less definite and are indicated merely by a local thickening of the lower Miocene strata on the south flank (Fig. 3). Apart from the supercap oil sands several wells on the west flank are producing from sands in the basal Miocene abutting the salt, but these accumulations are small and their significance is discussed later.

The top of the Oligocene at marker *X* corresponds with an abrupt change from the lower Miocene sand series to the shale section of the *Discorbis* zone. Two thin sand beds occur in this zone in the outlying wells on the southwest flank, both of which have been found gas-bearing.

The *Heterostegina* zone, although consisting mainly of shale, differs lithologically from the *Discorbis* zone in the occurrence of two and, in some places, three limestone sections. A relatively thin sand occurs close to the top of the *Heterostegina* zone on the northeast flank, but so far this sand has not been found productive.

[4] M. T. Halbouty, "Geology and Geophysics of Southeast Flank of Jennings Dome, Acadia Parish, Louisiana, with Special Reference to Overhang," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 9 (September, 1935), pp. 1308–29.

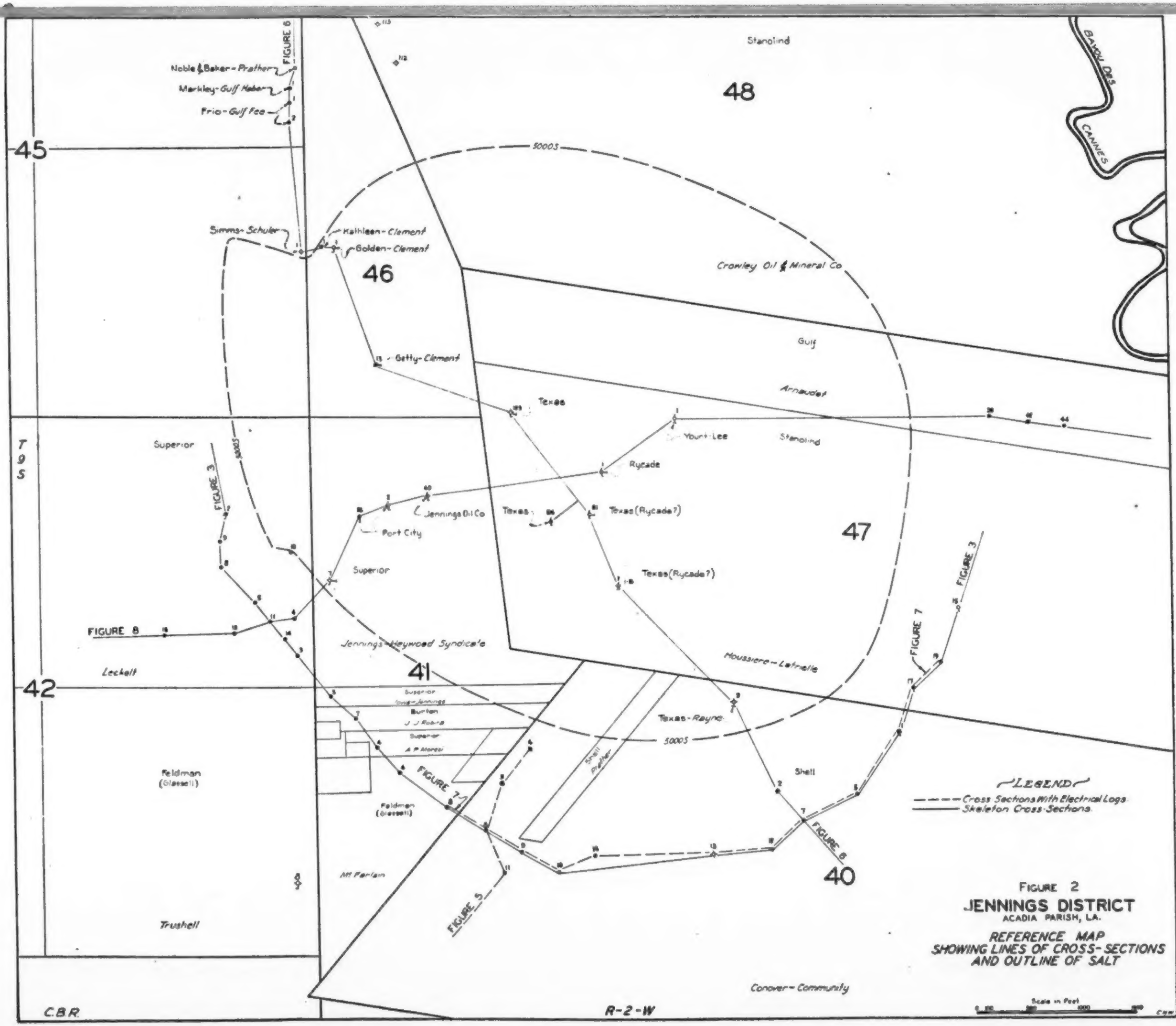


FIGURE 2
JENNINGS DISTRICT
ACADIA PARISH, LA.

REFERENCE MAP
SHOWING LINES OF CROSS-SECTIONS
AND OUTLINE OF SALT

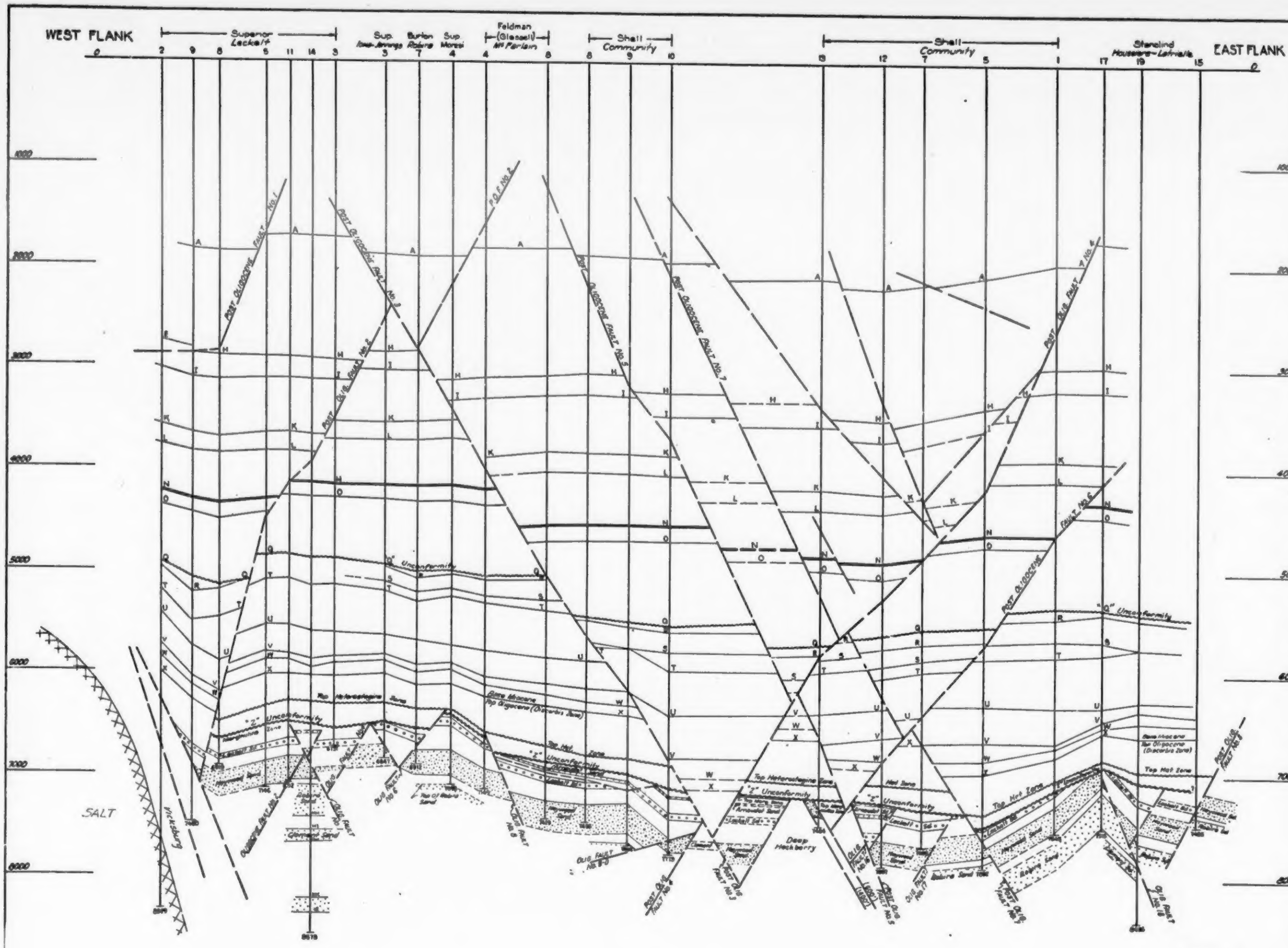


FIGURE 3

JENNINGS DISTRICT
ACADIA PARISH LOUISIANA
PERIPHERAL SECTION ALONG
SOUTHERN HALF OF DOME
Scale in Feet -- Vert. & Horiz.

The *Marginulina*-Frio zone contains eight sand intervals interbedded with well defined shales. As shown on the type log (Fig. 1) six of these sands are capable of yielding oil or gas and of these the Leckelt and Heywood sands contain by far the largest reserves of oil. Only one completion has been made as yet in the Arnaudet sand, which is oil-bearing on the south and east flanks; and the Robira sand section has only a comparatively narrow belt of production close to the southwest face of the salt plug. On the southwest flank the Clement sand is mainly gas-bearing and contains what appears to be a relatively thin oil column. On the northwest flank, however, the sands overlying the Clement sand are all barren, excepting a small gas accumulation in the Heywood sand in an isolated fault block. The Clement sand is the sole productive formation on this flank but has an oil column which is much thicker than that on the southwest flank.

Just above the top of the *Marginulina* zone is an important unconformity (marker *Z* on the type log, Fig. 1) below which occurs not only a change in sedimentation corresponding with the top of the *Marginulina*-Frio sand series, but also a completely different set of structural conditions. The contact between the *Marginulina* zone and the Frio shown on the type log is an arbitrary boundary which is not generally accepted. It was established in earlier days in the neighboring Iowa and Roanoke fields and was subsequently extended into Jennings, where it corresponds by paleontology with the top of the main member of the Heywood sand. Although on the basis of lithology, the top of the Frio might be placed at the top of the Heywood sand, the paleontological distinction is supported to some extent by the occurrence of different water levels in the upper stringer and main member of the Heywood sand in certain fault blocks on the south flank.

Two sands occur in the Frio below *Marginulina texana* and are shown on the type log at markers *MK* and *ML*. Neither of these sands, so far as encountered, has been oil-bearing, although oil showings were reported in a thin sand stringer above *MK* in Gulf Oil Corporation's Arnaudet No. 43 on the east flank.

Several wells have been drilled to the base of the *ML* sand and the stratigraphy is well established to this point. However, the information on the deeper beds is scant, and for this reason the type log (Fig. 1) was not extended below the *ML* sand. *Nodosaria blanpiedi* was observed in one well 870 feet below marker *MK* but whether in normal sequence has not yet been confirmed.

Several wells have penetrated deeper formations but ordinarily because of an accidental uplift of older strata. Thus, "Vicksburg" formation was reported by some companies on the north and west flanks, and deep "Hackberry" was drilled into on the south flank, but in each place the contact with the younger beds was faulted. It has not therefore been possible to ascertain the true position of these older beds in the stratigraphic column.

STRUCTURE

Except for the irregularity on the west flank the salt core of the Jennings dome is elliptical in outline. The long axis extends northwest-southeast and has a

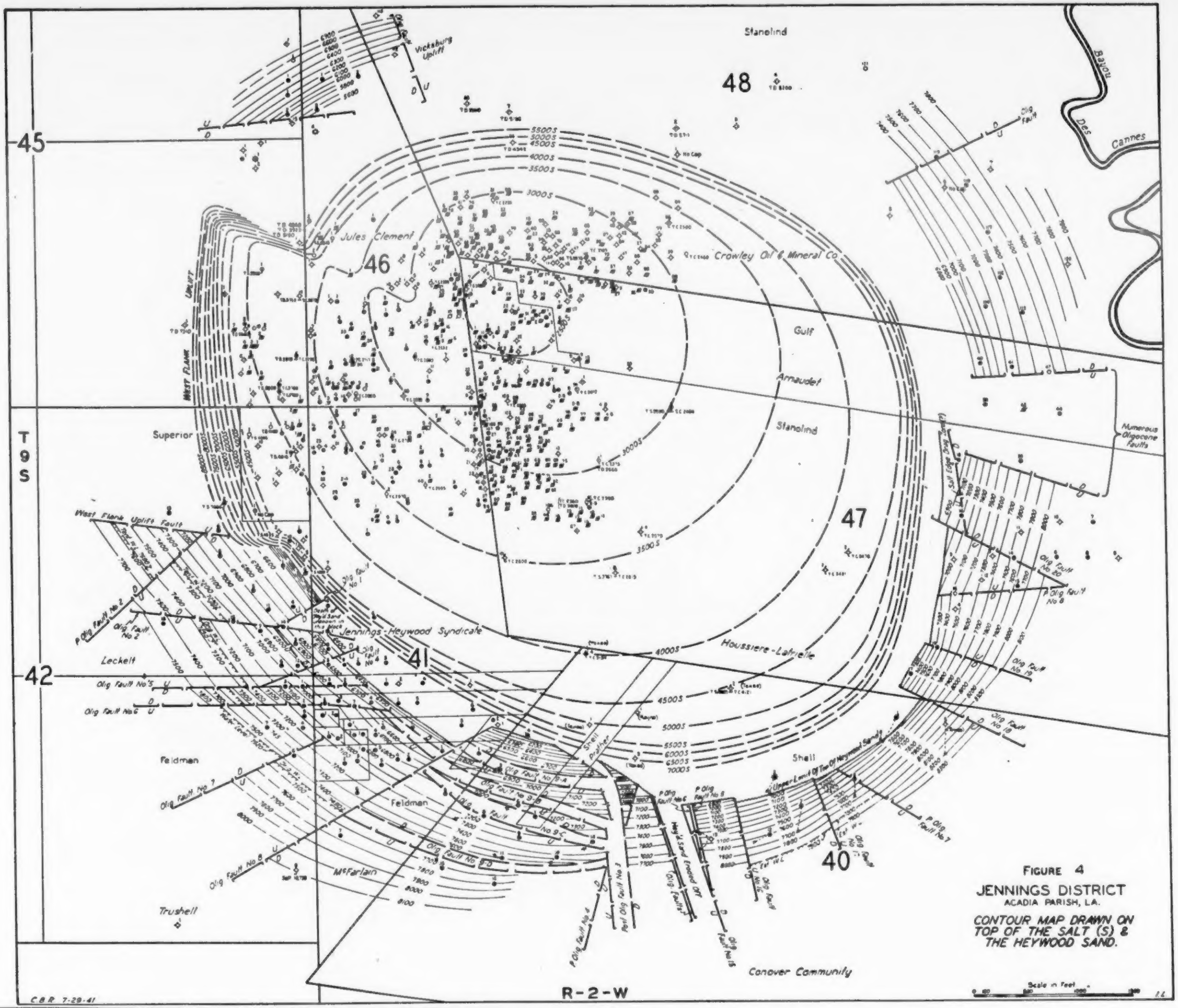


FIGURE 4
JENNINGS DISTRICT
ACADIA PARISH, LA.
CONTOUR MAP DRAWN ON TOP OF THE SALT (S) & THE HEYWOOD SAND.

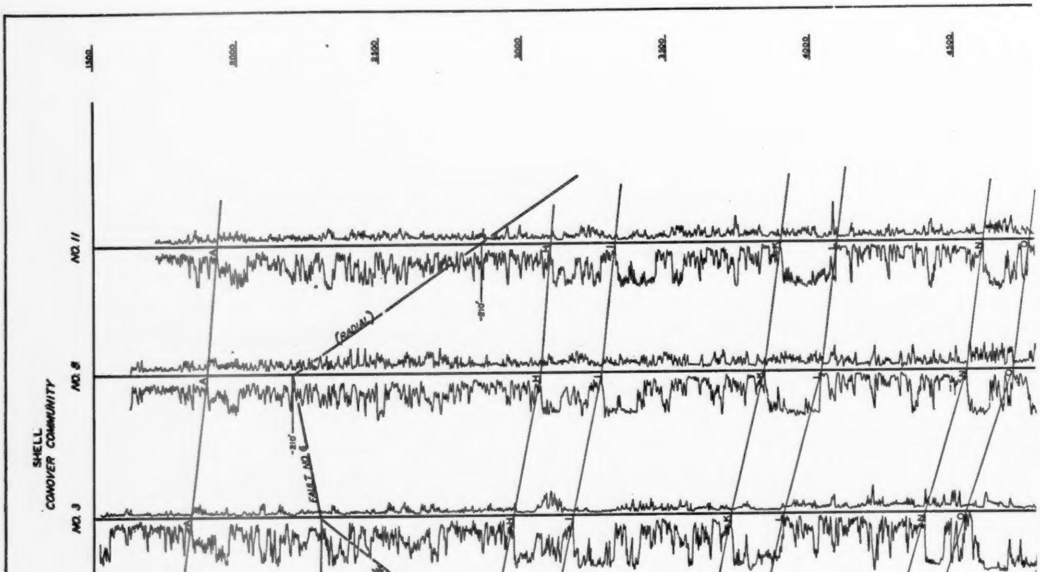
length of 6,450 feet at the 5,000-foot salt contour (Fig. 4). The short axis is 5,300 feet long at the same datum, and the area enclosed by this contour is 630 acres. The crest of the salt is eccentrically located in the north half of the plug, the highest point being a little less than 2,500 feet below the surface. A curious anomaly is the bulge in the salt on the west flank, which is wedge-shaped with the apex pointing toward the center of the salt plug. The maximum horizontal movement of the salt occurs at the north corner of the wedge where the contours have been displaced approximately 800 feet outward.

The salt dips steeply all around the dome; but on the southwest flank it was encountered in the deflected hole of Feldman's (Glassell) Trushell No. 8 at the depth of 10,735 feet. The bottom of the inclined hole was 1,750 feet from the vertical projection of the 6,000-foot salt contour and this indicates either a dip of about 60° from the horizontal (Fig. 5), or the presence of a salt shoulder on this flank. At the west end of the Shell Oil Company's Community lease, wells have penetrated a zone of high-pressure heaving shale dipping 50° from the horizontal. This formation may be a shale sheath on the salt face under which circumstance it lends some support to the possibility that the salt face itself may dip at a similar angle. Therefore, although the evidence is by no means conclusive, the inclined salt face on the south side of the dome and the sudden steepening of the salt shoulder on the north side may indicate that the salt plug is leaning slightly toward the north.

The salt plug is surmounted by a cap of which the area and shape conform closely with those of the salt. However, the cap rock is not uniformly developed but is considerably thicker on the southeast half of the dome where it reached a maximum thickness of 1,152 feet in The Texas Company's (Rycade) Houssiere-Latrielle No. 1-B, as against approximately 400 feet above the apex of the salt (Fig. 6). The cap rock also shows evidence of uplift on the west flank salt bulge, but the salt appears to have moved beyond the edge of the cap as the latter thins out and is not present in the wells which penetrated the salt close to the shoulder.

Little is known of the structure of the supercap formations. Electric logs are available from some of the relatively few wells drilled within recent years for supercap production, and in most of them the correlation is obscured by sedimentary changes and distortion of the strata by movement of the salt. Such correlation as can be worked out, however, points to the arching of the entire section of supercap formations. This is also borne out by the segregation of oil in the supercap sands, and by the remains of a surface expression. As shown in the chapter on "Accumulation," there is reason to believe that the supercap beds have also been lifted by the west flank salt bulge, similar to the cap rock.

The flank sediments reflect one structural unit or phase from the surface to the top of the *Heterostegina* zone, in which the dominant feature is the series of radial faults which traverse the entire stratigraphic column and form a system of alternating horsts and grabens round the periphery of the dome. Two such horsts embrace the entire southwest and northeast flanks. Between these a concentra-


SHELL
CONOVER COMMUNITY
NO. 11
NO. 8
NO. 3
NO. 4
(RADIAL)
FAULT NO. 6
POST OLIGOCENE
-210'
-190'
1500
2000
2500
3000
3500
4000
4500

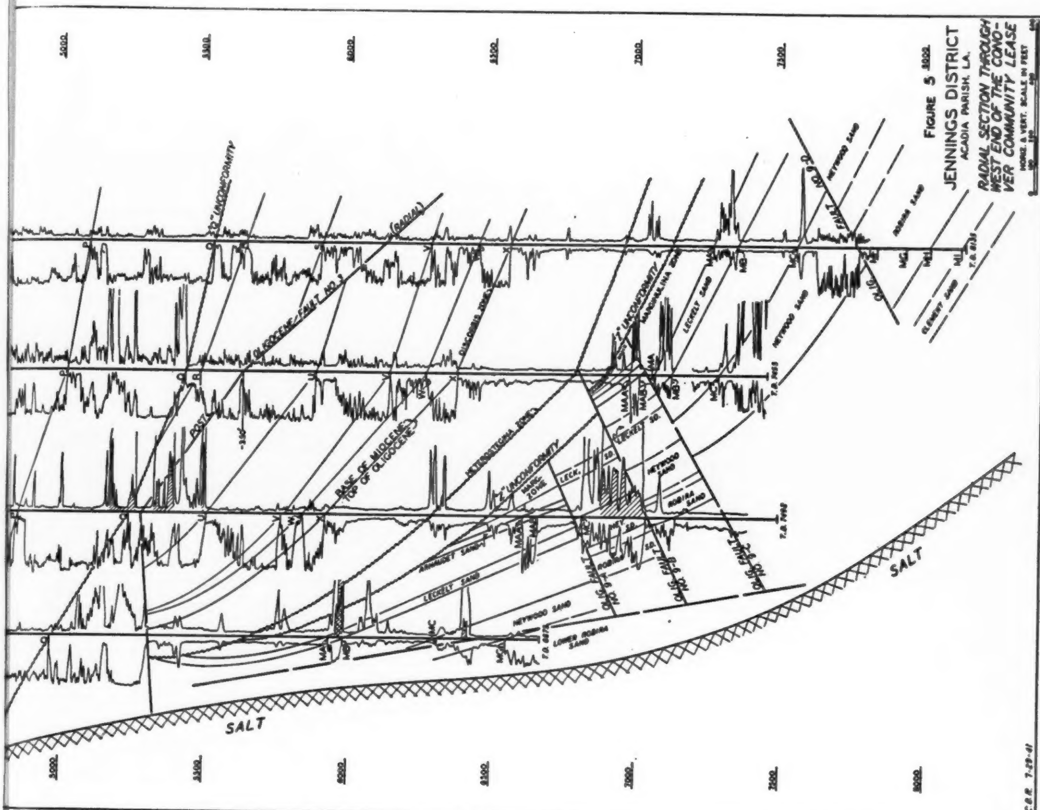


FIGURE 5
JENNINGS DISTRICT
ACADIA PARISH, LA.
RADIAL SECTION THROUGH WEST END OF THE CONOVER COMMUNITY LEASE

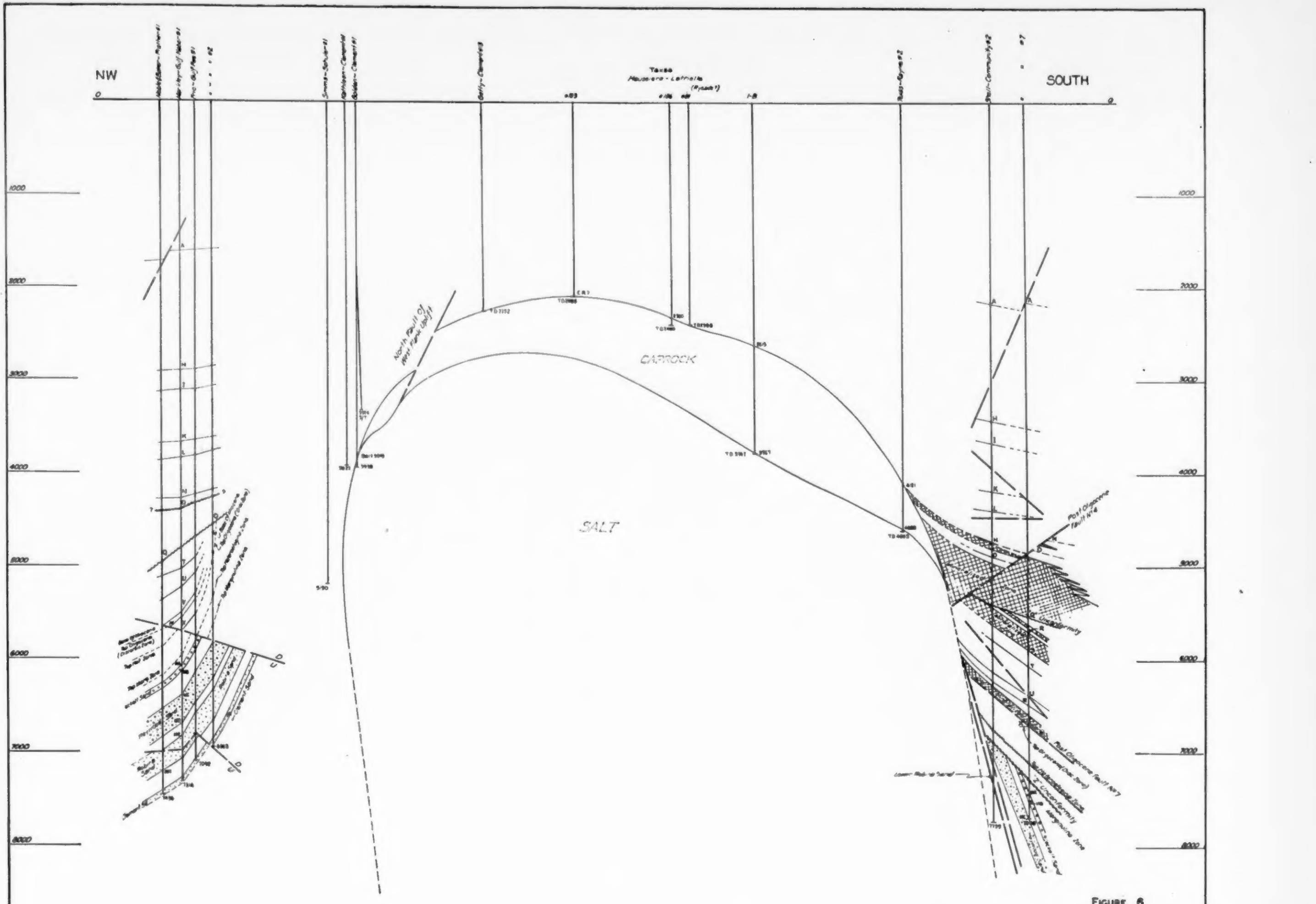


FIGURE 6
JENNINGS DISTRICT
ACADIA PARISH LOUISIANA
NORTHWEST - SOUTHEAST SECTION
THROUGH THE DOME
Scale in Feet - Vert & Horiz.

tion of faults dipping toward each other forms a graben on the south flank as shown on the peripheral sections (Figs. 3 and 7). This fault system is evidently of fairly recent age and, as shown later, appears to be a direct result of the west flank uplift.

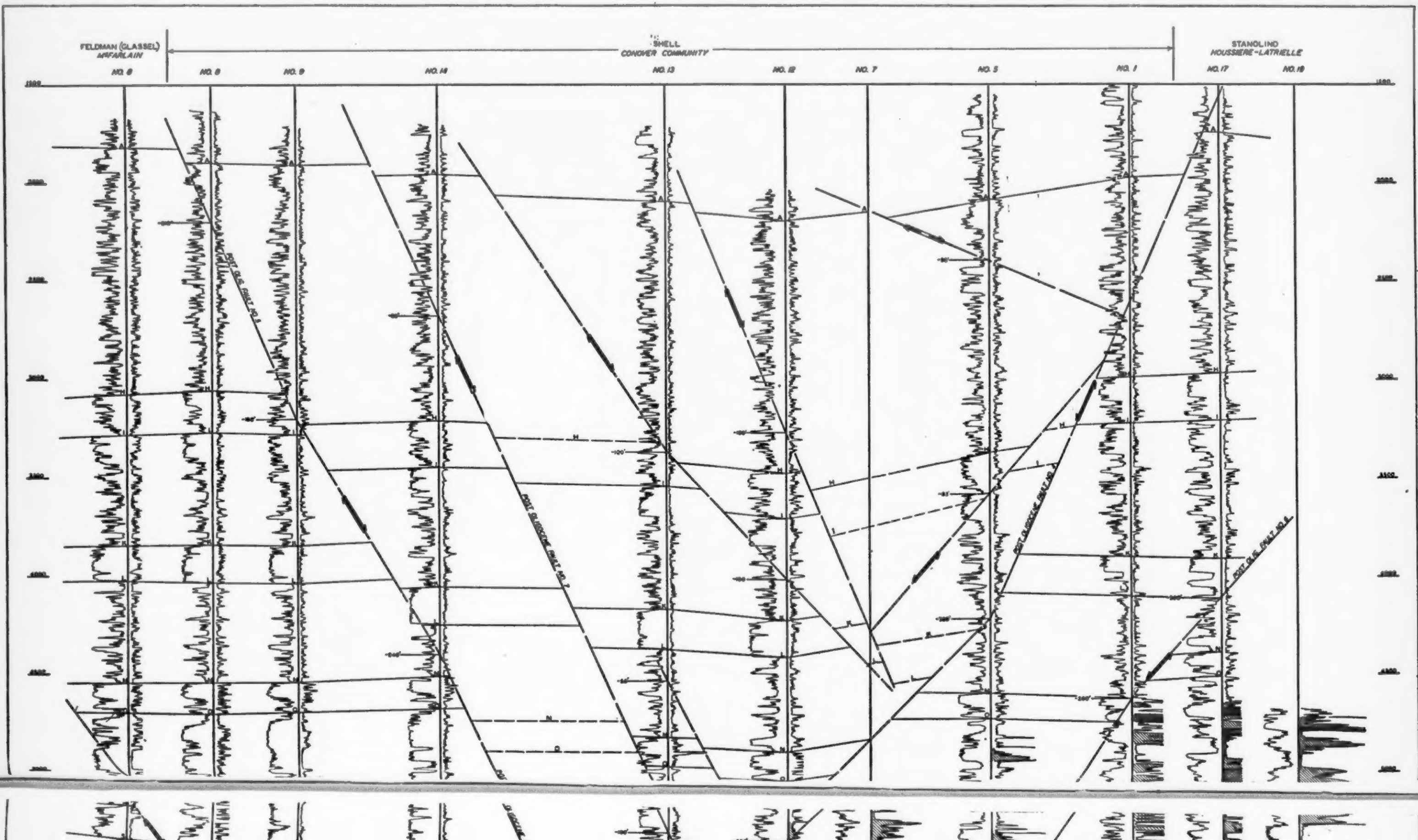
The flank sediments dip consistently outward from the salt plug as the result of tilting by the upthrusting salt, and the dip tends to increase with depth through gradual thickening of the strata away from the salt. However, a more definite change in dip occurs in the middle Miocene at marker *Q* on the type log (Fig. 1) and corresponds with an unconformity which can be traced along most of the periphery of the dome. Below this break the lower Miocene varies considerably in thickness around the flanks and reaches its maximum development on the south flank (Figs. 3 and 7).

On the northwest flank the *Q* unconformity closed a period of very strong movement in which the strata were tilted to such a high angle that there is evidence in one well of an overturn (Fig. 6). The top of this upturned mass was faulted prior to erosion and the upper Miocene sediments were deposited unconformably upon it. There is probably a second unconformity a short distance above that at marker *Q* although it is not so angular; it may result from later adjustment.

In the Oligocene, the *Discorbis* zone appears to be fairly regular in development, but the underlying *Heterostegina* zone changes so considerably in thickness that there is reason to believe that the top of this zone is unconformable with the *Discorbis* zone and that a few pre-unconformity faults are present, particularly on the southwest flank. The *Heterostegina* zone is thicker on the northeast flank than elsewhere round the dome, presumably as the result of less erosion.

Just above the base of the *Heterostegina* zone and apparently at the top of the lower *Heterostegina* limestone at marker *Z* on the type log (Fig. 1) occurs another unconformity. It is easily recognizable on a radial cross section because of the steeper angle of dip of the underlying *Marginulina*-Frio beds, of which the youngest disappear updip, and because of the underlying buried faults, which do not extend into the later deposits. Most of these faults range in throw from 100 to 200 feet, and in some wells the displacements are considerably in excess of this. The faults are also extremely numerous and are not restricted to any one flank of the dome. This gives a general impression of shattering of the *Marginulina*-Frio sediments, which in conjunction with the high angularity of the unconformity indicates an uplift of exceptional magnitude.

So far it has not been possible to attribute any general system or pattern to these faults, and, unless the evidence points to the contrary, they have been assumed radial. A system of four parallel tangential faults, however, has been worked out tentatively on the west end of the Conover Community lease, which probably extend well onto the southwest flank (Fig. 4). These faults dip toward the salt at a very flat angle as the result of the later tilting of the associated strata away from the salt plug.


FELDMAN (GLASSEL)
McFARLAIN
NO. 6
SHELL
CONOVER COMMUNITY
NO. 8
NO. 9
NO. 14
NO. 13
NO. 12
NO. 7
NO. 5
NO. 1
STANOLIND
HOUSSIERE-LATRIELLE
NO. 17
NO. 18
2000
2500
3000
3500
4000
4500
5000
POST OLIGOCENE FAULT NO. 7
POST OLIGOCENE FAULT NO. 1

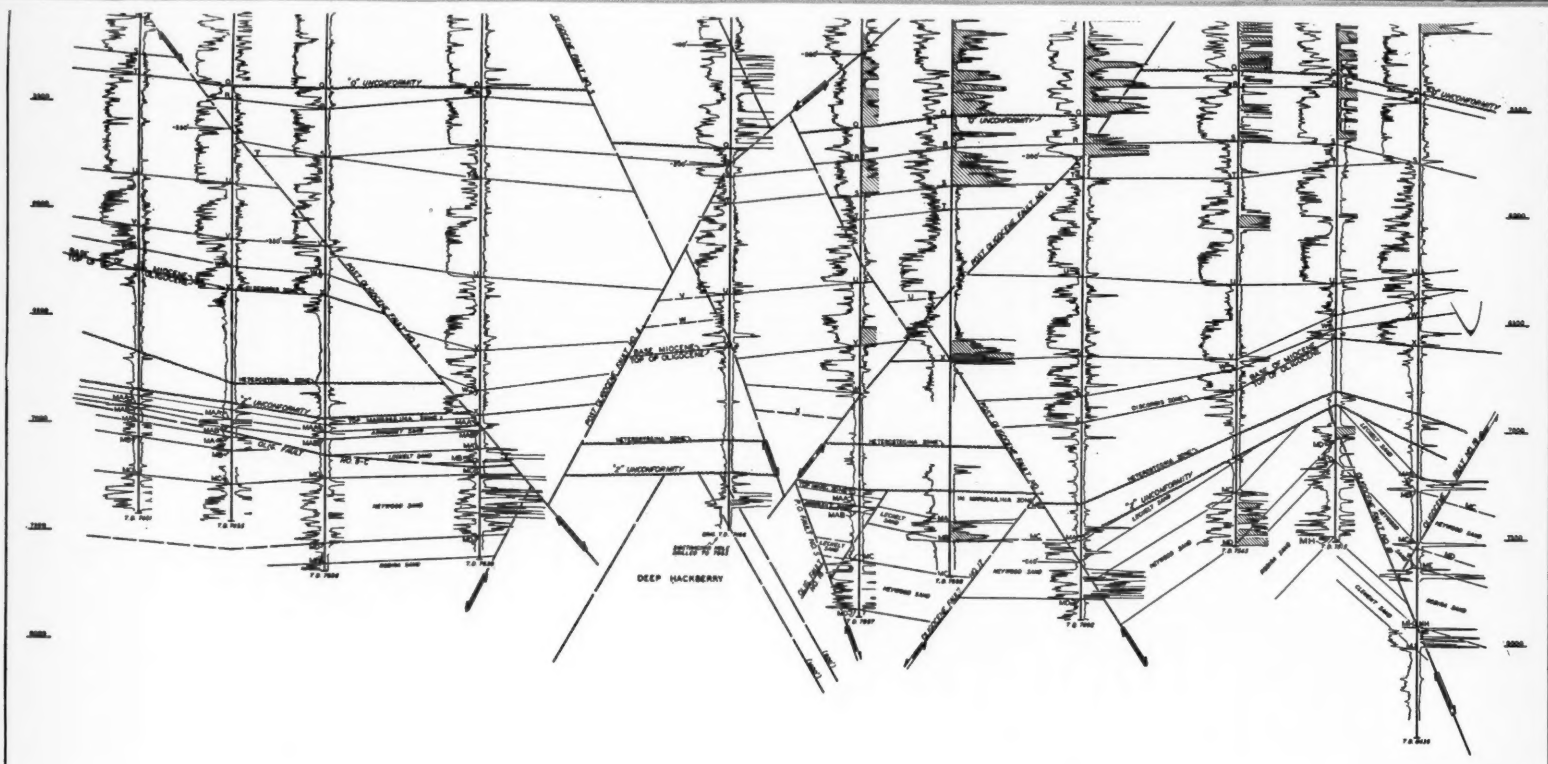


FIGURE 7
JENNINGS DISTRICT
ACADIA PARISH, LA.
PERIPHERAL SECTION
ALONG SOUTH FLANK
HORIZ. & VERT. SCALE IN FEET

C.B.R. 7-29-41

The Vicksburg has been reported from two different points on the flanks of the dome. One of these is at the south end of the west flank uplift where Vicksburg was encountered above the salt. The relatively high position of this formation (it was reported at 6,700 feet in Superior's Leckelt No. 2) leads to the conclusion that it is probably an old sheath against the salt raised to its present position at the time of the west flank uplift.

The other occurrence of Vicksburg is on the northwest flank where it was encountered in both the Stanolind's Crowley Oil and Mineral Nos. 112 and 113. In this case these two wells are on a radius, No. 113 being the outstepping well from No. 112. Both wells encountered Vicksburg above the expected top of the producing zone, namely, the Clement sand, whereas wells located on the west and on the same strike parallel with the salt edge encountered the Clement sand in a normal position. There is no evidence so far of a salt bulge on the north flank; it is probable, therefore, that this occurrence of Vicksburg is more than a sheath, and that it represents the edge of a wide uplift of flank sediments associated with a system of major radial faults. No wells have as yet been drilled on the east which would afford further information on this uplift; consequently, it is not possible to determine the age of the movement. However, the section of sediments cut out in the two Stanolind wells is so large and out of all proportion to the magnitude of the faulting already observed elsewhere in the Miocene, that it seems most likely that it occurred before the close of the Oligocene.

The productive area of the northwest flank lies in the graben formed by the Vicksburg uplift on the Crowley Oil and Mineral lease and the west flank uplift, and is a considerable distance from the salt edge. By referring to the northwest-southeast cross section (Fig. 6), it may be seen that in spite of the steep dip below the *Q* unconformity, the beds do not lie against the salt face. Presumably they are tilted against a series of older beds, but the age and structure of these strata are unknown.

MINERALIZED MIOCENE SAND SECTION

An interesting phenomenon of the Miocene is the mineralized sand section. All the sands below marker *N* as far as the base of the Miocene at marker *X* show secondary cementation depending on the position on the periphery of the dome. On the northwest, it is completely absent and on the southwest occurs only in wells close to the salt edge. On the east half of the dome, however, the mineralization is developed to an extraordinary degree.

When first penetrated on the east flank this section was thought to be cap rock, and cores containing anhydrite were reported. It was exceedingly difficult to drill because of its cavernous nature and the attendant loss of mud, and on the basis of seismic data, it was explained as an overhanging or "false" cap by M. T. Halbouty.[5] In places difficulty is still experienced in drilling through this

[5] M. T. Halbouty, *op. cit.*

formation, and in Shell's Conover-Community No. 7, for example, 40 days were taken to drill 720 feet of this material.[6]

Cap rock is generally accepted as being formed from the insoluble residues in the salt left behind by the leaching action of subterranean waters. However, three factors must be considered in this hypothesis: (1) the cap rock must be porous so that the water may reach the salt; (2) there must be a ready source of subterranean water; and (3) there must be an outlet for the solution of salt, otherwise the brine will become saturated and no further leaching action will take place: the Jennings dome is a good illustration of the manner in which this process worked. On the east flank of the dome the mineralized Miocene sands are in juxtaposition with the cap rock, which is thicker on this side than elsewhere (Texas' Houssiere-Latrielle No. 1-B recorded 1,152 feet of cap rock). It is then apparent that any heavy brine that formed at the contact of the cap rock and salt was able to flow over the shoulder of the salt and gravitate down the porous Miocene sands that dip away from the salt plug. Normal dilute salt water was then drawn into the cap rock from the top of the sand beds and circulated toward the salt to continue the leaching action. The concentrated brine naturally carried away some of those compounds in the salt, which would otherwise have accumulated to form cap rock, and they were deposited in the pores of the sand. The brine followed the lowest path first, that is, the bottom of the sand bed or zone, and deposition of the cap rock material took place along this path. Deposition was also greatest at the points nearest the cap rock and graded off from the dome as the content of cap-rock compounds in the brine diminished. The tendency was then for the level of mineralization to rise as the lower zones were cemented, and for the action to start in an overlying sand bed, when the truncated updip ends of the sand had become completely mineralized. This is very clearly demonstrated by the electric logs where the resistivities of the mineralized sands increase toward the bottom of each layer, and the tops of the sand beds are left uncemented, although overlying beds have suffered cementation.

On the southwest flank of the dome the cap rock has been forced completely through the Miocene sand section, and only a moderate degree of mineralization has occurred in the sands. Apparently conditions were not so ideally suited on this flank for extensive leaching of the salt, or it may be possible that the cap rock was tilted in its present position (Fig. 6) before mineralization started, thus inducing the maximum outflow of mineralizing water toward the south and east flanks.

An important point in the theory outlined is that the mineralized sand section on the east flank remained in juxtaposition with the cap rock for the whole period during which the enormous quantity of salt was dissolved which gave rise to the large volume of cementing material in the Miocene sand. Nevertheless, this action did not leave a vast hollow in the salt, otherwise there would be some

[6] Neil Williams, "Shell Overcomes Caving to Bring in Coastal Well," *Oil and Gas Jour.*, Vol. 38, No. 30 (December 7, 1939), pp. 55–58.

evidence of collapse of the cap rock and surrounding strata, and it can only be assumed that the salt was continually rising from below to take the place of that which was dissolved.

The east-west cross section (Fig. 8) shows that the mineralized zone forms, as it were, a root or anchor for the cap rock; on the plan the mineralization extends around almost half the periphery of the dome. If the salt rose at a greater rate than could be taken care of by leaching, or if, as seems more probable, the mineralization were complete and no further leaching could take place, then in order to resume its normal upward movement the salt would have to shear the bond between the cap rock and the mineralized zone. On the other hand, no such bond is present on the west flank, and this would form an easier path by which to relieve pressure from below. This seems to have occurred because the cap rock has been tilted upward on the west side, and a bulge has formed in the salt in the manner of a V-shaped sector that has been lifted upward and outward from below. This phenomenon is shown in Figure 4.

Several interesting points arise from the foregoing discussion on the mineralized sand section. The more important are briefly: the point of growth of the cap rock is at its base, the newest deposit being at the contact of the salt and cap rock;[7] the cap probably increased in thickness all the time that the mineralization was taking place; bending and faulting of the flank sediments after the sands had become mineralized led to the formation of cracks and joints which now constitute the cavities encountered during drilling.

STRUCTURAL HISTORY

A summary of the foregoing brings out the following points in the structural history of the Jennings dome.

1. An uplift of the salt mass occurred just after the close of *Marginulina* time, which fractured and elevated the overlying sediments. A high, upthrown block may have formed on the north side, which would account for the occurrence of the Vicksburg uplift on this flank.

2. The sediments were eroded from the crest of the dome, and the *Heterostegina* zone was deposited unconformably over the structure. The angle of unconformity was high, and the original uplift must, therefore, have been considerable, the salt probably rising to within a short distance of the top of the *Marginulina* sediments.

3. A smaller uplift, with some additional faulting and erosion, occurred after the *Heterostegina* zone had been deposited.

4. Normal deposition continued throughout the *Discorbis* zone and lowermost Miocene beds, accompanied by slow, continuous upward movement of the salt, which caused the beds to tilt gently and thicken away from the dome. The movement was evidently centered north of the present axis of the plug as the basal Miocene sediments are thickest on the south flank.

[7] Ralph E. Taylor, "Origin of the Cap Rock of Louisiana Salt Domes," *Louisiana Geol. Survey Bull. 11* (August, 1938), pp. 91–92.

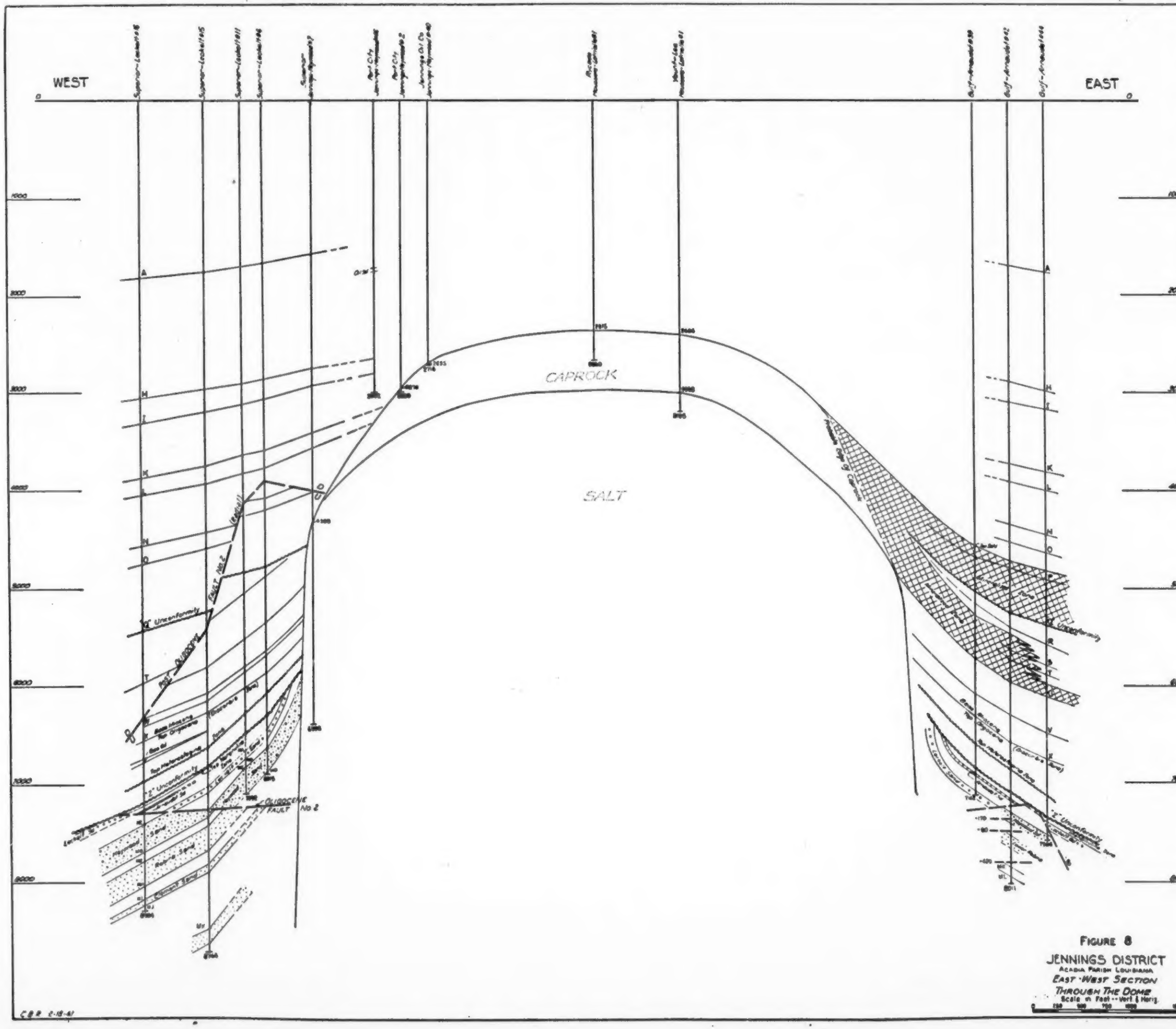


FIGURE 8
JENNINGS DISTRICT
ACADIA PARISH LOUISIANA
EAST-WEST SECTION
THROUGH THE DOME
Scale in Feet -- Vert. & Horiz.

5. An uplift occurred in the salt at the time corresponding with marker *Q* in the Miocene. This is recorded by a gentle unconformity along most of the periphery of the dome, except on the northwest flank where excessive tilting of the sediments occurred. At this time the salt had probably completely pierced the Oligocene and was well within the basal Miocene.

6. Through gradual and steady upward movement of the salt the cap rock came into juxtaposition with the thick Miocene sand section, particularly on the east flank, and the sands became mineralized. The upward movement of the salt was counteracted by solution, and the top of the dome remained more or less static.

7. Increased uplift of the salt, or resumption of normal continuous uplift, following the complete mineralization of the Miocene sands resulted in increased pressure below the cap rock. The pressure could not break the bond with the mineralized Miocene sands and gave rise to (1) expansion of the salt on the west flank in a V-shaped wedge, (2) tilting of the cap rock, (3) fracturing of the entire section of flank sediments through tension faulting, and (4) migration of the oil into the supercap sands, a point which will be discussed later.

One of the most important factors in the history outlined in the foregoing seven paragraphs is the development of numerous unconformities and other variations in thickness of the strata. Not only do they denote stages in the upward movement of the salt, but they also show evidence of horizontal shift of the uplift. It has already been pointed out that certain of these anomalies are not evenly developed all around the dome, but vary laterally as well as radially. In other words, the center of uplift has not always coincided with the same vertical axis but has moved horizontally, and the point of maximum erosion has shifted accordingly.

Fundamentally, the salt may be expected to follow the path of least resistance, and the crest of the salt mass will rise wherever the overlying strata bend or break under pressure applied from below by the salt, whether it be at the center of the plug or at the edge. By taking this hypothesis one step further, it is conceivable that the entire salt core may be deflected off true vertical, resulting in shoulders on the salt flank or in an inclined axis. The extreme case is, of course, the deflection of the salt around the edge of a thick cap and the eventual formation of a spine or offset plug.

In the case of Jennings the apex of the salt is eccentrically located to the north (Fig. 4), evidently as the result of differential uplift of the top of the salt. It will also be noticed on the map that the steepest flank of the salt occurs on the north side, whereas the south flank is more gentle, and the outlying well, Feldman's (Glassell) Trushell No. 8, encountered salt at 10,735 feet. It is therefore concluded that the axis of the Jennings salt plug leans toward the north, and that an overhang, if such it may be called, probably occurs on the north side. Future uplifts of the salt should take place on the west flank, where the bulge has already

started, and, therefore, the salt mass now appears to be in the process of changing from a north to a westerly inclination.

The opportunity has arisen of checking the application of this hypothesis to other domes, and there seems but little doubt that a number of similarly inclined salt plugs exist in the Gulf Coast region—indeed, the conclusion has been reached that salt plugs in general do not rise in a vertical line from the mother salt bed but follow a crooked path, the direction of which is governed by the structure and strength of the overlying deposits, whether cap rock or sediments.[8]

ACCUMULATION OF PETROLEUM

The accumulation of oil which was originally developed at Jennings occurred in shallow sands in the upper Miocene overlying the cap rock. Production was later obtained from lower Miocene sands downdip toward the west, and as late as 1938 the Superior's Leckelt No. 10 encountered a stray accumulation in a basal Miocene sand butting against the western edge of the salt.

Flank development has disclosed the presence of several sands in the Oligocene formations, which are capable of prolific oil or gas production under appropriate structural conditions. These sands are shown on the type log (Fig. 1).

The faulting which took place at the close of *Marginulina* time had a very definite effect on the accumulation of oil and gas, as it broke the *Marginulina*-Frio sediments into many small fault blocks in which there is now considerable variation in the water levels and the oil and gas contacts. Thus, the water level in the Heywood sand varies from 7,250 feet in the middle of the Leckelt lease to 7,520 feet on the adjacent Trushell lease, and similar differences occur in almost every fault block. Furthermore, the Shell drilled two wells, Community No. 2 and No. 3, which found only gas in the Heywood sand in structural positions relative to the salt which are oil bearing in other blocks on the southwest flank.

Apart from the west flank the *Marginulina*-Frio sands are evenly distributed on the periphery of the dome, and with certain exceptions the productive belt is continuous. However, these sands have not yet been found in normal position against the west flank bulge, and such recent wells as have been drilled there at the north end of the Leckelt lease have found salt or so-called Vicksburg.

It is clear, then, that the salt uplift and bulge broke the continuity of the *Marginulina*-Frio sands, and it now appears that this rupture allowed the accumulations of oil and gas along this arc to escape to the shallow supercap sands. Evidence of drainage from the sands in the adjacent fault blocks is also apparent on the northwest flank where only the Clement sand is productive, and on the southwest flank where the wells on the Leckelt lease, nearest the uplift, show a narrower belt of production compared with wells farther south.

[8] Donald C. Barton, "Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Salt Domes of Texas and Louisiana," *Gulf Coast Oil Fields* (Amer. Assoc. Petrol. Geol., December, 1936), p. 75.

Figure 4 shows that productive wells were completed in the supercap sands overlying the entire sector of the west flank uplift from the center of the dome to the shoulder of the salt. The oil also migrated from this uplift into the adjacent sands above the apex of the salt plug. Outside these two areas no supercap production was obtained. As the field was discovered on seepage evidence, it appears that migration to the supercap sands is of fairly recent origin; and since the accumulation occurred in successively deeper sands toward the edge of the salt uplift, it is possible that migration was not complete, and that the water levels had not adjusted themselves at the time the field was discovered. This would not only date the period of migration as fairly recent, but also the salt bulge and the associated radial faults elsewhere on the flanks of the dome. This premise is substantiated to some extent by the presence of a distinct topographic "high" above the dome; although this feature has been much eroded, and the existing remnant is about $\frac{3}{4}$ mile east of the west flank.

ACKNOWLEDGMENTS

The writer is indebted to J. B. Dorr, research paleontologist, Shell Oil Company, Incorporated, Houston, Texas, who very ably coöperated in this study by investigating the Oligocene paleontology. Acknowledgment is also due O. Wilhelm, area subsurface engineer for the Shell Oil Company, Incorporated, Houston, Texas, who has given a great deal of assistance and useful criticism on this investigation of the Jennings structure.

The writer also wishes to acknowledge the assistance of the geologists of the Gulf Refining Company, the Stanolind Oil and Gas Company, and the Superior Oil Company in Lake Charles, Louisiana, who made available well logs and other important information.

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VOL. 27, NO. 8 (AUGUST, 1943), PP. 1123-1156, 11 FIGS.

ANSE LA BUTTE DOME, ST. MARTIN PARISH, LOUISIANA[1]

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Lafayette, Louisiana

ABSTRACT

Anse la Butte is on the west border of St. Martin Parish, Louisiana, in the south-central part of the state, within the belt of Gulf Coast salt domes. Drilling leading to the discovery in 1901 of shallow production and domal material was prompted by the presence of gas seeps and surface relief. Deeper flank production was discovered by Glassell and Glassell in 1940 following subsurface study and geophysical work. The production is from sands ranging from Pleistocene to Chickasawhay Miocene in age, with principal production from the upper Catahoula Miocene. Oil accumulation is found at depths from a few hundred to below 9,000 feet depending on structural position.

It is a piercement-type dome with salt found as shallow as 160 feet. Formational dips around the salt plug range up to 75°, being nearly everywhere slightly less than the surface of the contiguous salt mass. Strong radial faulting is noted.

Through August, 1942, 4,269,264 barrels of oil had been produced, with a total ultimate recovery indicated, from sands now known, of about 32 million barrels. Development of flank sands at shallow and intermediate depths is now probably complete, but recent drilling suggests the possible presence of additional deeper flank reserves.

INTRODUCTION

Because of its accessibility, and long and interesting history, the Anse la Butte dome has been described in detail by numerous competent authors. G. D. Harris in several publications from 1899 to 1910 (9–12),[3] Lee Hager in 1904 (8), N. M. Fenneman in 1905 (5) and 1906 (6), D. C. Barton between 1925 and 1930 (1–3), to mention only a few, have described in detail the history of development and the subsurface structure as it was known at the time of their respective publications. Howe and Moresi (14) in 1933 contributed an excellent and comprehensive review of all previous knowledge of the dome, together with their analyses of its geologic problems.

The purpose of this paper is both to supplement Howe and Moresi's historical study and to provide a reinterpretation of subsurface conditions in the light of subsequent data. Only enough reference is made to phases covered by the previous literature to give the background for the present picture. Abundant evidence derived from the improved methods now in use has permitted a more exact and complete study of the structural and stratigraphic conditions than has been possible heretofore, and has resulted in several major revisions of previous conceptions.

The writers hope that this paper may serve both to bring the history of this dome up to date and to furnish a guide for further study of the many problems remaining unsolved.

LOCATION

The Anse la Butte dome is on the west edge of St. Martin Parish, Louisiana, its regional geographic location being shown on the plat map (Fig. 1). Accessible

[1] Manuscript received, November 14, 1942.

[2] Consulting geologist and paleontologist.

[3] Numbers in parentheses indicate references at the end of the article.

by State Highway 43, it is 7 miles east of Lafayette and 4 miles west of Breaux Bridge, centering in Sec. 117, T. 9 S., R. 5. E. A part of the old Morgan's Texas and Louisiana Railway, now a branch line of the Texas and New Orleans (Southern Pacific) Railroad, passes through the field from east to west.

The area has a general elevation above sea-level of about 15 feet, draining west to the Vermilion River and east to the Bayou Teche. It lies close to the west

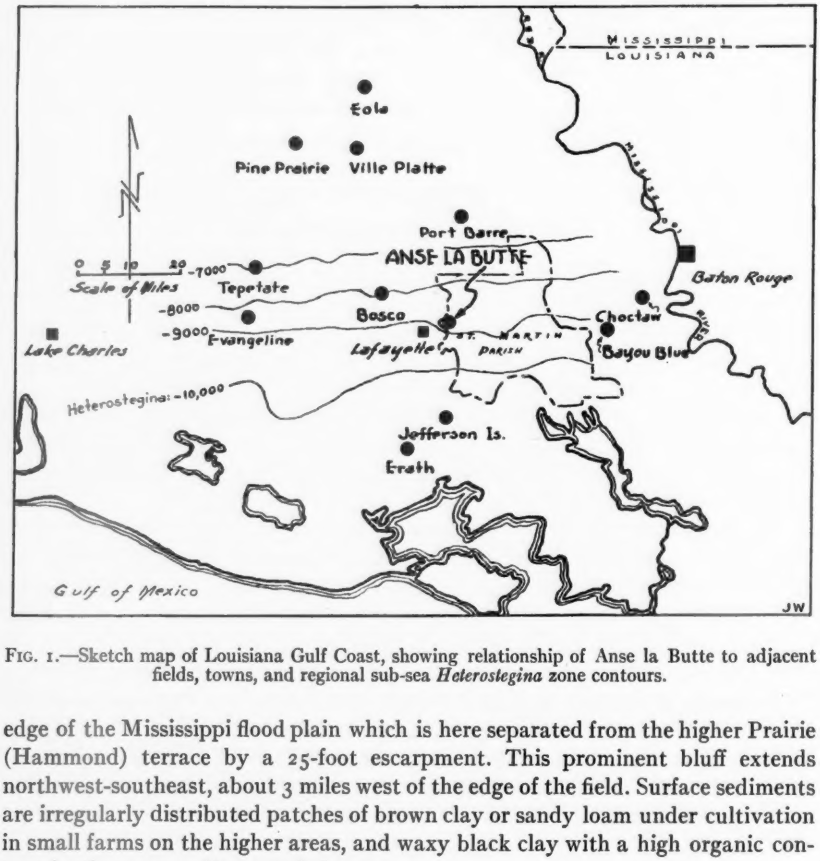


FIG. 1.—Sketch map of Louisiana Gulf Coast, showing relationship of Anse la Butte to adjacent fields, towns, and regional sub-sea *Heterostegina* zone contours.

edge of the Mississippi flood plain which is here separated from the higher Prairie (Hammond) terrace by a 25-foot escarpment. This prominent bluff extends northwest-southeast, about 3 miles west of the edge of the field. Surface sediments are irregularly distributed patches of brown clay or sandy loam under cultivation in small farms on the higher areas, and waxy black clay with a high organic content in the surrounding wooded swamp.

The dome has strong surface expression in the form of a mound rising 18 feet above the surrounding swamp with a diameter approaching 1,000 feet. Immediately south of the mound is Flat Lake, a shallow depression overlying the apex of the salt plug. It has been suggested by Barton (2) and others that this lake is caused by solution of the underlying salt, which is here overlain with only about

160 feet or less of sediments. Howe and Moresi (14; pp. 73–76) have very completely described the surface expression and appearance of this dome.

The name is derived from these prominent physiographic features; in the "Cajun" French patois locally spoken, "Anse la Butte" may be freely translated "Lake by the Hill."

HISTORY

According to Harris (9; p. 138), the first interest in Anse la Butte was elicited, before the turn of the century, by the quantities of gas which issued from the then heavily wooded lake and from the surrounding marsh. The initial attempts to drill for oil were made in 1899, but production was not established until 1901, after interest in the discovery of oil at Spindletop prompted the drilling of several new shallow wells by the Heywood Brothers, the Moresi Brothers, and others near the "butte." In 1907 the Lake Oil Company drilled several wells just north of the "butte" which produced 3,000 to 4,000 barrels daily on open flow from super-salt Pliocene sands at a depth of about 1,900 feet. Intermittent drilling by the Humble Oil and Refining Company, the Gulf Refining Company, and others continued for several years, reaching successively deeper sands.

Between 1920 and 1927 the Lafayette Salt Company, and from 1923 to 1930 the Star Salt Corporation, manufactured table salt commercially by evaporation of brine obtained from wells drilled into the dome at its apex. A total of 119,630 short tons was produced from 1920 to 1930 by these two companies. In early 1942 a similar extraction plant was placed in operation by the Gordy Salt Company.

A few unsuccessful tests, both for shallow super-salt and deeper flank production, were drilled between 1925 and 1940. One, a north flank well drilled in 1929 by the Yount-Lee Oil Company, produced over a short period a total of 750 barrels, probably from the "Breaux" series, thus constituting the first deep flank producton. In 1937 the Stanolind Oil and Gas Company drilled a flank well in Section 46, southeast of the highway, which found salt at 4,600 feet and was then plugged back and deflected from the dome, reaching a depth of 6,300 feet. This well logged what is now known as the Patin sand at 4,800 feet, which might have provided a small producer had it been tested.

By 1939 the total daily production of the field had dropped to about 50 barrels per day of low-gravity oil pumped from shallow wells on or near the "butte." Prior to 1940, 129 tests were drilled, mostly close in to the apex of the dome, of which 39 gave limited oil production, two resulted in gas wells, five were for salt, and the remainder were dry. This development was participated in by many companies, including the Heywood Brothers, the Moresi Brothers, the Lake Oil Company, the Deborah Oil Company, the Anse la Butte Oil Company, the Bowie Oil Company, Ayers Brothers, the Humble Oil and Refining Company, the Gulf Refining Company, the Yount-Lee Oil Company, the Louisiana Crusaders Oil Company, the Stanolind Oil and Gas Company, and numerous individuals.

The current flank drilling campaign was started, after subsurface study and

exploration with reflection seismograph, by Glassell and Glassell with their M. Breaux Estate No. 1 on the southwest flank of the dome. This well was completed, February 7, 1940, producing 339 barrels per day of 38.9° gravity oil on a 12/64-inch choke through perforations from 4,630 to 4,650 feet in the Breaux sand. Having established flank production here, a location was made by the same operator on the southeast flank adjacent to the Stanolind well previously mentioned. This test was the first producer from the Patin sand topped at about 4,700 feet. A drilling program by the Stanolind, Glassell, the Crosby Drilling Company, and others followed on the southeast flank, with Glassell also active in the southwest area. This further exploration resulted in the discovery of several additional productive Miocene sands, among them the Moresi and prolific Martin sands, located just above and just below the Breaux and Patin sands, respectively.

Glassell, seeking deep production in the *Marginulina* sands similar to that found around the Evangeline (Jennings) dome, Acadia Parish, Louisiana, drilled Tony Tortoris No. 1 farther out on the southwest flank. This test went to 9,800 feet, possibly reaching beds of Chickasawhay (basal Miocene) age. No salt was found and the *Marginulina* sands of the lower Catahoula, although carrying oil, were very poorly developed, and extensive testing of several horizons failed to result in commercial production. Subsequent wells have confirmed the poor development of the *Marginulina* sands around the Anse la Butte dome.

On the extreme east flank, W. R. Davis and Company in May, 1941, completed Alexis Voorhies No. 2 at 9,420 feet as a good oil well in a sand tentatively assigned to the Hackberry zone of the Chickasawhay. At the depth of 9,780 feet, the Stanolind Oil and Gas Company in July, 1942, established commercial production from a sand in the same zone in J. C. Nickerson No. 1, on the extreme flank several miles northwest of the apex of the dome in Lafayette Parish. Future development of these sands may prove them an important additional reserve.

From 1940 to September, 1942, 97 wells were drilled, 59 being commerical producers and 38 dry and abandoned. Of the producers, seven are completed in the various shallow "stripper" sands, 5 in sands of the Breaux series, 25 in the Patin sand, 20 in the Martin series, and 2 in the Hackberry zone. Of the dry holes, 8 were tests for deep *Marginulina* or Hackberry zone production, 16 were attempts to extend production from the upper Miocene sands, and 14 were shallow "stripper" tests. The locations of the different wells and areas referred to are shown on the development map (Fig. 2) and the map of productive areas (Fig. 5). The exact nature and characteristics of each of the producing sands will be further discussed.

MAPS

Originally the land title was divided in a pattern of Spanish and French land-grant sections irregular in size and shape, generally elongate, parallel with the present highway and extending from Vermilion River on the west to Bayou Teche on the east. These grants were then subdivided parallel with the longer bound-

aries in order to provide riparian rights to as many families as possible. These long slender tracts have since undergone further division, so that the leases, particularly immediately surrounding the "butte," consist of numerous small irregular farms 5 to 10 acres in extent. No attempt has been made to superimpose a standard section pattern on the existing grid. The land situation is further complicated by the apparent existence of two overlapping section systems, making exact description and identification of tracts very difficult.

Howe and Moresi (14; p. 53) have commented on the difficulty of correct map descriptions.

The most difficult problem in preparing the report of this dome lay in the construction of a map. The fundamental reason is that disputes regarding claims to these lands have caused the section boundaries and numbers to be changed on the maps of the State Land office. Therefore, different maps of this dome, including those of the major oil companies, are inconsistent in locating the section boundaries, numbering the sections and locating the wells.

The same problem exists to-day, intensified by the greater number of wells, continued subdivision of tracts by filial inheritance of estates, and by numerous boundary and ownership disputes because of the enhanced land and mineral values. The writers have carefully studied all existing maps and parish land records, together with many surveys made by the operating companies, and believe that the development map presented (Fig. 2), while still inaccurate, may eliminate some of the previous difficulties. Wherever a section was found to bear two numbers, both are shown, with the less used number smaller and in parentheses. Because of the many small tracts, only the section pattern, without ownership, is employed for the structure maps.

PRODUCTION

The early wells at Anse la Butte were drilled with primitive rotary equipment in its various stages of development. Some wells were standardized for "drilling-in," but cable tools could not be used for normal drilling because of the unconsolidated water-bearing sands and gravels in the surface formations. Drilling practice during the current flank campaign has been rather uniform. Rotary tools were used exclusively, a string of $10\frac{3}{4}$-inch surface casing was set through the fresh-water sands usually to about 1,000 feet, and $5\frac{1}{2}$-inch casing was cemented on bottom through the pay zone. If this zone was thick, approximately the bottom third above water was perforated; if thinner (100 feet or less) and composed of fairly clean uniform sand, only the top third was shot. The wells were then completed through 2-inch tubing by washing with water and swabbing.

In order to conserve materials, it has been the recent practice to make dual completions in wells showing oil in two sands. As one sand produces through the casing, and one through the tubing, the drilling of twin wells is eliminated.

Anse la Butte produced through August, 1942, 4,269,264 barrels of crude oil of gravities varying from 18° to 30° in the "stripper" wells, from 35° to 38° from

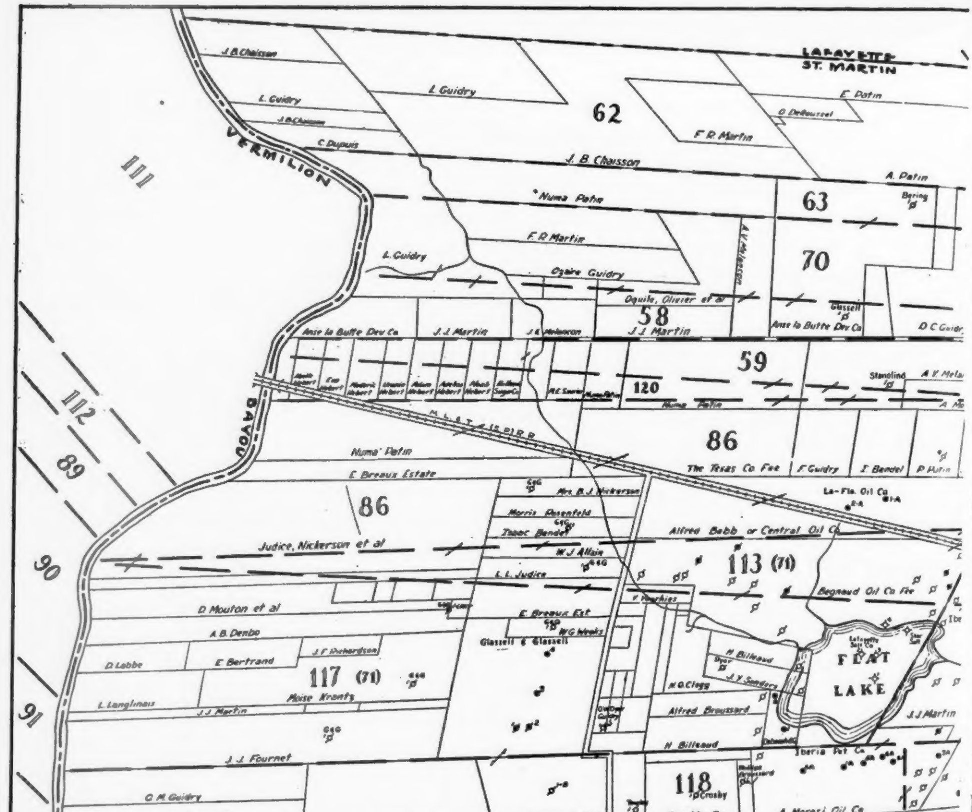
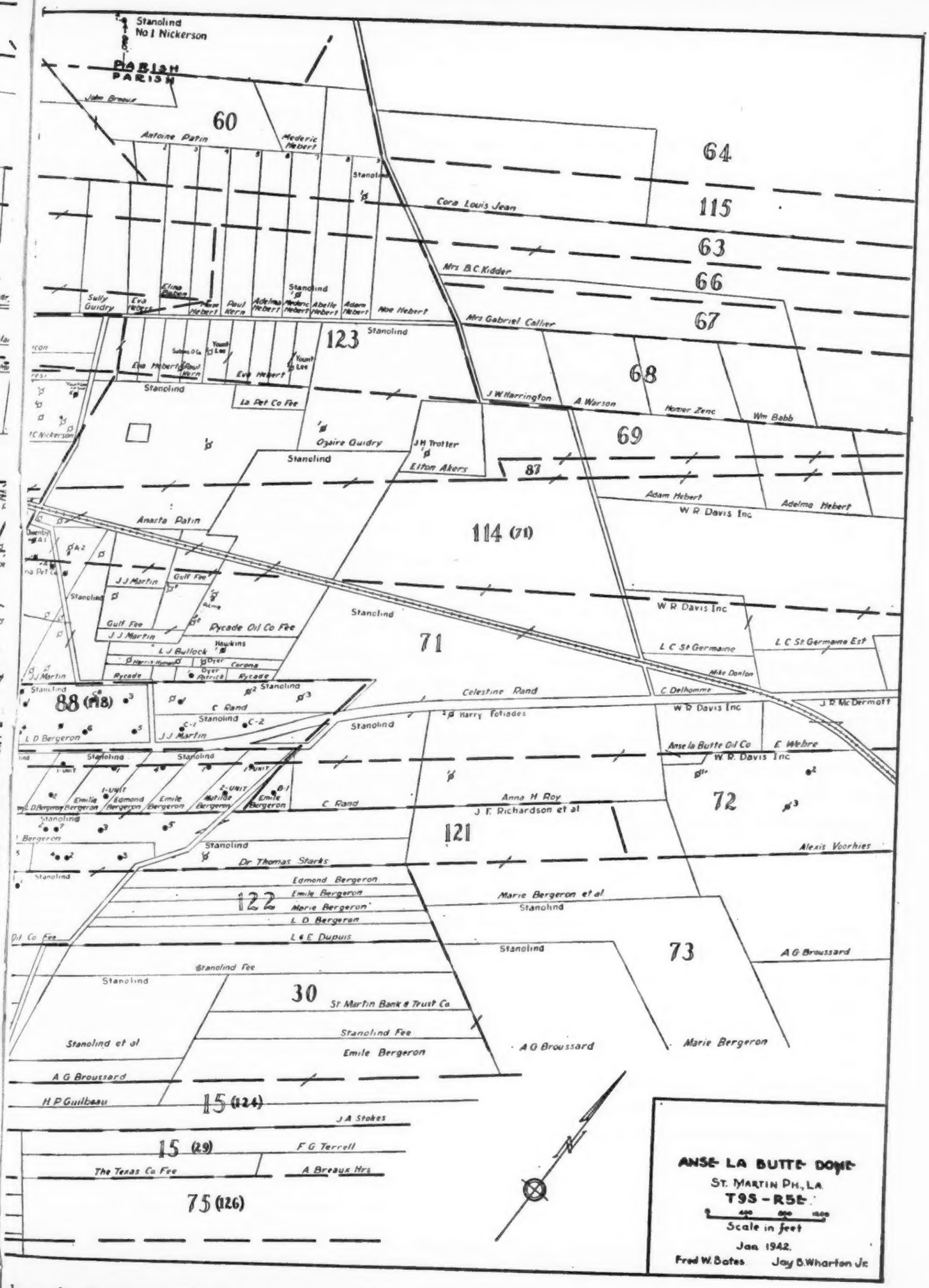


FIG. 2.—Development map of Anse la Butte



dome, showing wells and land ownership.

the upper Miocene sands, and from 29° to 31° in the Hackberry zone wells. It is brownish green, paraffine-intermediate base crude, sulphur-free, of desirable characteristics, and brings a price of $1.04 to $1.20 per barrel, depending on gravity.

TABLE I

Anse la Butte Production in Barrels by Years*

Year	*Stripper Sands*†	*Breaux Series*‡	*Patin Series*	*Martin Series*‖	*Hackberry Series*	*Total*
1900–09	332,078	—	—	—	—	332,078
1910–19	205,464	—	—	—	—	205,464
1920–29	148,384	750	—	—	—	149,134
1930–39	243,917	—	—	—	—	243,917
1940	77,669	99,347	184,202	—	—	361,218
1941	163,777	222,494	774,463	241,830	40,035	1,442,599
1942**	91,544	130,962	629,052	666,191	17,105	1,534,854**
Total	1,262,833	453,553	1,587,717	908,021	57,140	4,269,264

* Figures for 1933 to 1939 inclusive secured from Lockwood's *Southern Louisiana Reference Report*, remainder from Minerals Division and the Bureau of Scientific Research and Statistics of the Louisiana Department of Conservation.
† Includes Moresi sands.
‡ Includes Bergeron, Patrick, and Breaux sands.
‖ Includes Castille, upper and lower Martin sands.
** Includes production through August 31, 1942.

Working-tubing pressures are approximately 850 pounds and bottom-hole pressures vary from 2,000 to 3,000 pounds in different sands. Gas-oil ratios are very low, averaging 400 cubic feet of gas per barrel of oil. Potential tests give an average of more than 200 barrels on a 9/64-inch choke. These figures apply principally to the recent flank wells which provide about 95 per cent of the present production of the field.

A part of the oil is taken by the Standard Oil Company of Louisiana by pipe line to the refinery at Baton Rouge, Louisiana; the remainder of the oil is handled by Glassell and Glassell's pipe line to Bayou Teche and thence by barge to refineries by way of the Intracoastal Canal.

PRORATION

Few piercement-type domes have been developed on a regular spacing pattern or under regulations controlling drilling or production. Anse la Butte was among the first domes on which regulated development was attempted. At Spindletop, Jennings, Anse la Butte itself (prior to 1940), and other such domes, due to the small size of the tracts, relatively shallow but thick oil sands, and high per-acre yields, development followed an exceedingly dense pattern, many wells being only a few feet apart. To overcome the tragic waste of equipment, financing, and natural resources resulting from such methods, Anse la Butte was placed under strictly enforced regulations shortly after the discovery of flank production. It is believed that the eminent success of these regulations warrants a discussion here of their provisions.

On September 1, 1940, the Minerals Division of the Louisiana Department of Conservation placed in effect a special field order (20) regulating the drilling and

production of wells at Anse la Butte. A spacing pattern of one well to 5 acres was established, with a 3-acre minimum. The last well on any one tract was permitted a tolerance up to 7 acres if the excess acres could not be unitized with adjoining acres. For wells to the Breaux sand level or deeper, drilling permits were not issued for tracts smaller than 3 acres unless proved that pooling with contiguous tracts was impracticable. For leases smaller than 3 acres and impossible to unitize, the allowable as calculated for a 3-acre unit was decreased in direct proportion to the ratio of the true size of the tract to the 3-acre minimum. For sands at less depth than the Breaux, minimum units of 2 acres are permitted; and penalized as previously specified if of smaller size.

The total daily allowable assigned to the field is apportioned equitably to each producing sand. The daily allowable production of oil for any well is based half on its potential production as determined periodically by the State engineers, and half on the amount of its assigned acreage. The part of the individual well allowable based on "potential" is determined for any well as that proportion of half the total allowable of the sand which is given by the ratio of the potential production of that well to the sum of the potentials of all wells completed in the same sand. Similarly the "acreage" allotment is that proportion of half the total allowable production in that sand, which is determined by the ratio that the acreage allotted to the well bears to the total acreage assigned to all wells in that sand.

The daily allowable for any particular well *A*, completed in sand *S*, may be more simply expressed by use of the actual mathematical relationships.

$$\text{Potential allowable for } A = \frac{\text{Potential of } A}{\text{Sum of potentials of all wells in } S} \times \frac{\text{Total allowable allotted to } S}{2}$$

$$\text{Acreage allowable for } A = \frac{\text{Acreage assigned to } A}{\text{Total acreage producing from } S} \times \frac{\text{Total allowable allotted to } S}{2}$$

$$\text{Total daily allowable for } A = \text{Potential allowable for } A + \text{Acreage allowable for } A$$

These formulas apply only to units between the minimum and maximum acreage limits. Acreage can not be assigned in excess of the maximum limit. For wells on units smaller than the minimum, the daily allowable as calculated for the minimum acreage is penalized in direct proportion to the acreage deficiency. Any well incapable of producing its calculated allowable is given an allowable equal to its capacity under the prescribed testing conditions. If unable to flow naturally, the allowable is computed using the well's actual acreage but the smallest natural potential recorded for any well in that sand. Artificial lift may then be employed to secure production up to that allowable. Wells showing a gas-oil ratio in excess of 1,000:1 are penalized to that rate of flow producing only the amount of gas which would be furnished by the normal allowable of the well at a 1,000:1 gas-oil ratio. A schedule is computed and published monthly showing the factors used, and the resultant allowable daily production for each well in the field.

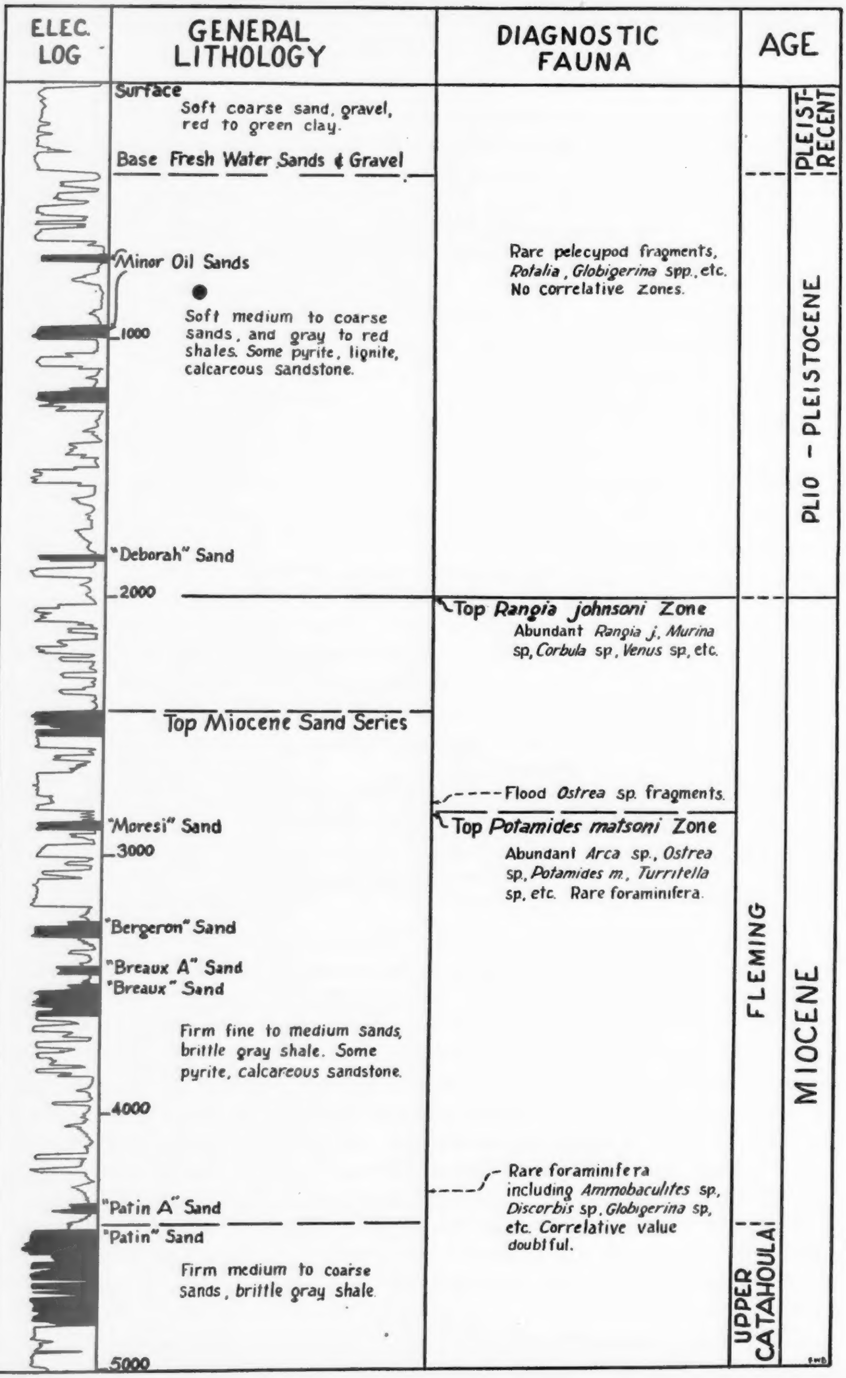


FIG. 3.—Generalized columnar section of formations and producing sands encountered at Anse la Butte above 5,000 feet, and diagnostic faunal zones.

In addition it is further stipulated that no part of the unit may be more than 500 feet from the well-site, and that surveyed plats of the unit be submitted and approved prior to drilling. Before an allowable is granted, certified copies of a directional survey showing the location of the bottom of the hole to be within the bounds of the unit must be submitted. Copies of the driller's log and electrical log must also be filed. The regulations outline approved methods of drilling, setting casing, and completing wells. This procedure has proved effective and satisfactory, since it reduces unnecessary development and loss of reservoir energy but is at the same time flexible enough to be applied to the complex problem of developing small leases and multiple sands.

For September, 1942, the field had a total daily allowable of 6,294 barrels, of which 3 per cent is allotted to production from the shallow "stripper" sands, 11 per cent to the Breaux series, 38 per cent to the Patin sand, 44 per cent to the Martin series, and 4 per cent to the Hackberry zone sands. The average allowable per well for each group is: "stripper" sands 20 barrels, Breaux series 90 barrels, Patin sand 105 barrels, Martin series 145 barrels, and Hackberry zone 180 barrels.

STRATIGRAPHY

The stratigraphic section in wells on the Anse la Butte dome is predominantly Miocene in age, consisting of soft thick sand bodies and intercalated shale beds. These sediments are overlain by about 2,000 feet of younger, lithologically similar beds which are Pliocene to Recent in age. No true Oligocene has been encountered to the greatest depth reached, 9,940 feet.

Correlation is accomplished almost entirely by the comparison of electrical logs, as most of the wells stop in the upper Catahoula, which here contains very few paleontological markers. Limited correlation was attempted by the writers on macro-fossil zones as later described. Micropaleontologic markers are abundant and diagnostic in the Marine Catahoula (or so-called "middle Marine Oligocene"), the lower Catahoula and deeper, but to date little development has reached these levels. In exploration for deep flank production, foraminiferal correlation will be found invaluable.

The columnar sections (Figs. 3 and 4) have been prepared from parts of typical electrical logs of wells in different structural positions, so that each oil-bearing zone could be shown at or near its producing depth with characteristic thicknesses and sand development. The salient lithologic and paleontologic characteristics of each formation are given on these charts.

For convenience, the formations are described in descending order as encountered by the drill rather than in order of deposition.

Surface.—Clay and sandy clay are exposed on the surface. Harris referred the surface to the Oligocene, though Howe and Moresi (14; p. 76) say "it is certainly Pliocene or younger." With the possible exception of material in and immediately surrounding the "butte," it is probably Recent fluviatile in origin.

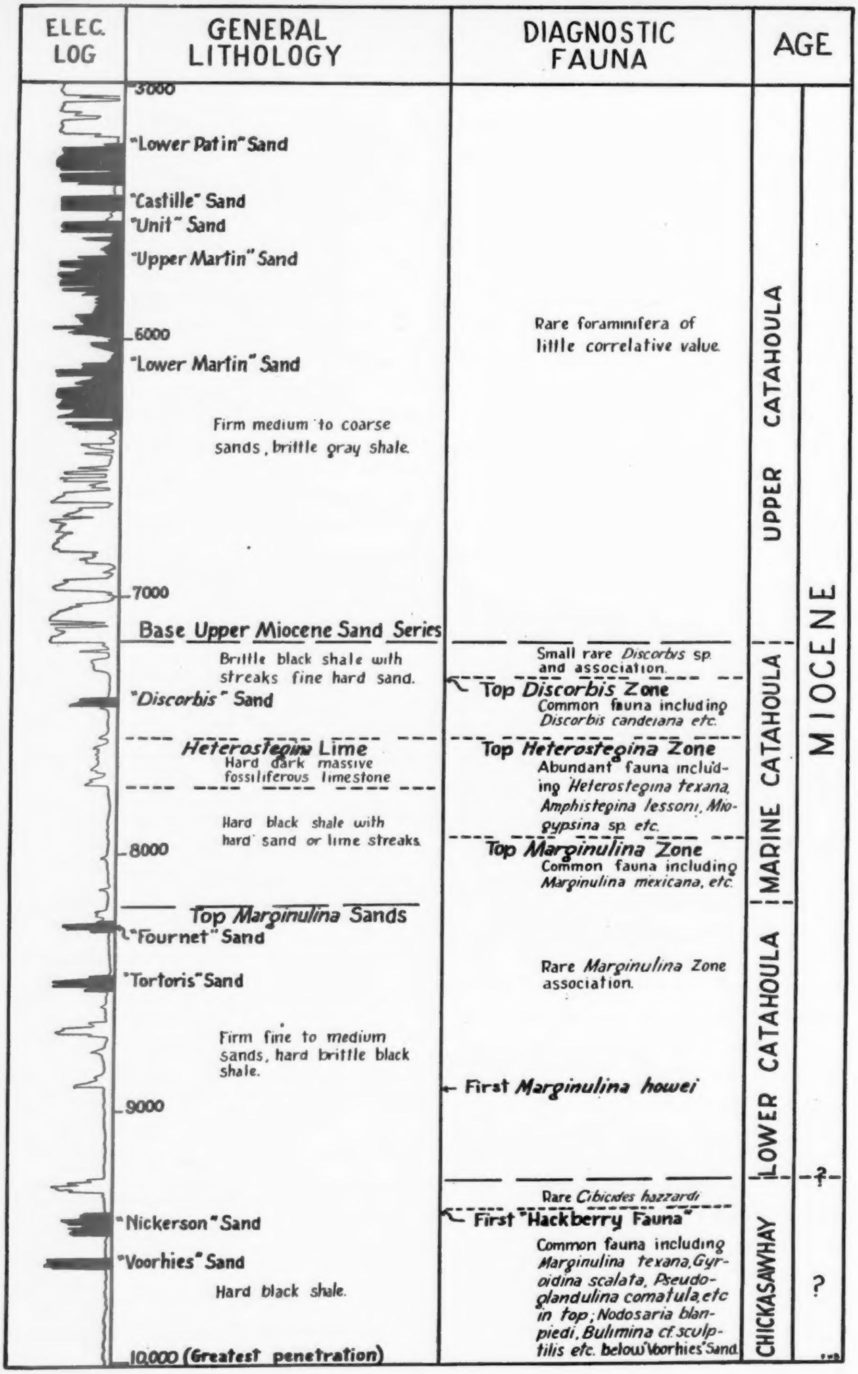


FIG. 4.—Generalized columnar section of formations and producing sands encountered at Anse la Butte below 5,000 feet, and diagnostic faunal zones.

Post-Miocene.—Since no differentiation between the Pleistocene and Pliocene beds is possible because of the absence of dependable criteria, these beds have been grouped as post-Miocene. The sediments in this group range from 1,000 to 3,000 feet thick in the wells, an average flank well penetrating about 2,000 to 2,400 feet. Of this thickness the top 300 to 800 feet is composed of medium to coarse-grained sand or small gravel, containing fresh water. Below, to the top of the Miocene, are soft red and green clays and irregular streaks of soft medium-grained sand.

Paleontological examinations of samples from this section have revealed only rare pelecypod shell fragments and very rare *Rotalia beccarii* and *Globigerina* spp. Paleontological correlation has never been attempted in this section. Determination of the base of the fresh-water sands, best accomplished from electrical logs, is the only point of economic interest.

Fleming Miocene.—The top of the Miocene and top Fleming is marked by appearance in the well cuttings of abundant *Rangia johnsoni* with other associated pelecypods, principally species of *Ostrea*, *Venus*, *Corbula*, *Murina*, *et cetera.* The pelecypod zone in which *Rangia johnsoni* is found is generally the shallowest occurrence of shell fragments in important quantity.

Near the middle of the Fleming occurs a flood of gray shell fragments containing no distinctive forms but consisting principally of *Ostrea* fragments and easily identifiable by color. This marker is limited in occurrence and value. Immediately below the "gray shell" zone is the first occurrence of the gastropod *Potamides matsoni* and pelecypod *Arca* sp. This is probably the best correlative faunal zone in the Fleming at Anse la Butte, and is found about 600 to 800 feet above the base. Abundant but inconsistent lignite appearing in well cuttings at several points, suggests, together with the variegated shales, a lagunal or shallow-marine origin for a part of these sediments.

The Fleming consists of large bodies of fine- to medium-grained soft porous sand interbedded with thin red and gray shales. Where this formation is entirely present it averages about 2,500 to 3,500 feet in thickness of which nearly 80 per cent is sand. A persistent massive sand zone noted about 400 feet below the top of the Fleming has been designated the top of the "Miocene Sand series" for local correlation. This series is between 1,500 and 2,500 feet in thickness, with an interval of about 500 feet, predominantly shale, extending below it to the base of the Fleming. Lateral persistence of sands improves with increased penetration into the Miocene. With care the sands can be correlated fairly accurately across the entire area.

Catahoula Miocene.—Confusion exists both in the literature and in usage, about the proper nomenclature and age designation of sediments of the *Discorbis* and older zones. Although recognizing that the problem can not yet be solved with certainty, and that each of the several variant opinions has merit, the writers have in this study divided the Catahoula into upper, marine, and lower

Catahoula, as advocated by Israelsky (15; pp. 381–82).[4] In the reference cited, it is suggested that

> For convenience we may, when the "Middle Marine Oligocene" is present, use the names Upper Catahoula, . . . "Marine Catahoula," and Lower Catahoula, bearing in mind the Upper and Lower Catahoula will vary according to the development of the "Middle Marine Oligocene" or "Marine Catahoula." Where the Marine phase is poorly developed (updip) we simply recognize Catahoula (undifferentiated).

Howe (13; pp. 405–17) correlates the *Discorbis, Heterostegina,* and *Marginulina* zones as a marine phase of the Catahoula, and speaks of them as "the so-called Middle Oligocene." He places the Tampa limestone of Florida as equivalent to this part of the Catahoula, noting that it includes an abundance of the diagnostic *Discorbis candeiana* and associated micro-fauna of the *Discorbis* zone as well as a large part of the *Heterostegina* zone assemblage. Howe emphasizes

> the strong probability that the *Heterostegina* zone and perhaps the *Discorbis* and *Marginulina* zones also should be correlated with the . . . Tampa limestone as the "down-dip" or seaward facies of the Catahoula.

As such, the entire Catahoula should properly be assigned to the Miocene.

F. B. Plummer (17; p. 701), in describing the Cenozoic systems in Texas, says

> The sub-surface middle Oligocene strata [which he names only as *Discorbis, Heterostegina,* and *Marginulina* zones] may be the down-dip extension of the lower or middle portion of the Catahoula formation in outcrop.

Hazzard, Blanpied, Alexander (18; p. 7), and others have presented a classification and description of the Miocene strata of Mississippi, in which the Miocene was subdivided, in descending order, into "Catahoula," Upper Chickasawhay member, Lower Chickasawhay member and Bucatunna member, each given formational status under the heading "Catahoula Group." They recognize

> that the word "Catahoula" is used not only as a group name but as a formational name, a procedure which is not at all satisfactory from the standpoint of stratigraphic nomenclature. . . . The term "Catahoula" is used . . . to signify a sequence of non-marine sands and clays . . . lithologically similar to the sands and clays of the type Catahoula in Catahoula Parish, Louisiana, and which . . . overlie marine beds assigned to the Miocene.

The writers approve of this nomenclature, suggesting further that the term "Catahoula group" be dropped, leaving the Gulf Coastal Miocene composed of the three formations: Fleming,[5] Catahoula, and Chickasawhay. In the writers' opinion there is not evidence of sufficient lithologic or paleontologic change to warrant placing the division between Miocene and Oligocene strata at the base of the Fleming; hence, the entire Catahoula should be considered Miocene in age.

Upper Catahoula.—In a few wells it has been possible to designate the top of

[4] The school of geological thought dissenting from this designation places the top of the Oligocene at the top of the *Discorbis candeiana* zone as shown in Figure 4.

[5] The Fleming is not present in the Mississippi outcrop; hence, it does not appear in the classification suggested in the preceding paragraph; its Miocene designation and superposition on the Catahoula is unquestioned in the literature.

the upper Catahoula as being the first sand below the first occurrence of a rare small *Discorbis* sp., accompanied by *Ammobaculites* sp., *Globigerina inflata* and *Rotalia beccarii*, which are found in basal shales of the overlying Fleming. The top of the prominent Patin sand series has been arbitrarily designated as marking the top of the Catahoula, since this is the only point of easily recognizable geologic characteristics in this part of the section.

The upper Catahoula is encountered at depths ranging from about 4,300 feet where it pinches out against the salt, down to 6,000 feet in wells drilled on the outer flanks. It consists primarily of thick, soft, medium-coarse porous sand bodies with minor breaks of gray shale, the latter increasing in prominence in the lower half. It is 2,600 to 3,200 feet in thickness where the entire section is present. Only in the eight deep flank tests has the complete section of upper Catahoula been penetrated.

Marine Catahoula.—This section consists of about 1,000 feet of brittle gray shale, with a few thin tight sand bodies in the upper part and the hard gray crystalline abundantly fossiliferous *Heterostegina* limestone in the middle. In the Stanolind Oil and Gas Company's Nickerson No. 1, on the north flank, this limestone was 350 feet in thickness; in wells on the southwest and southeast flanks, only about 100 feet.

Six wells have drilled through this member of the Catahoula, which is easily identifiable on the electrical log by a characteristic change from a section predominantly sand into one of almost solid shale. No difficulty is experienced in recognizing it from the well cuttings by micro-paleontology, as there are at least three well defined faunal assemblages present. All of these wells are strongly faulted because of their proximity to the salt mass, so none has yet shown a complete section.

The top of the Marine Catahoula is determined from cuttings by the first presence of a small *Discorbis* sp. plus *Globigerina inflata*, *G. bulloides*, *Elphidium sagrum*, *Rotalia beccarii*, *Siphonina advena*, *et cetera*. Thus the top of the Marine Catahoula corresponds with the top of the "*Discorbis* zone." From 100 to 200 feet below the *Discorbis* zone the fauna is augmented by *Discorbis candeiana*, *Robulus americanus*, *Uvigerina* spp., and *Eponides antillarum*, used here as in other Gulf Coast fields to designate the "restricted *Discorbis* zone." These foraminifera are accompanied by a typical but non-diagnostic micro-fauna increasing in abundance with depth.

The most distinctive assemblage is found from 300 to 500 feet below the top of the Marine Catahoula, being encountered in and below the *Heterostegina* limestone before mentioned. This group includes the first appearance of the well known marker, *Heterostegina texana*, as well as an abundance of associated forms including, in addition to the *Discorbis* assemblage, *Amphistegina lessoni*, *Globulina* spp., *Clavulina communis*, *Miogypsina* cf. *vesicularis*, *Textularia* spp., *Nodosaria* cf. *vertebralis*, *Quinqueloculina seminulum*, *Q. crassa*, *Nonion* spp., *Sorites* sp. *Lepidocyclina* sp., ostracoda, *et cetera*.

From 250 to 400 feet below the *Heterostegina* limestone, the *Marginulina* zone is marked by the first occurrence of *Marginulina mexicana* and *M. mexicana* var. *vaginata*, which may be accompanied or preceded by *Marginulina idiomorpha*. Included in the *Marginulina* fauna are *Ammobaculites* spp., *Bolivina perca*, *Cibicides concentricus*, *Dentalina* spp., *Discorbis* cf. *bertheloti*, *Eponides antillarum*, *Lagena sulcata*, *Nodosaria* cf. *vertebralis*, *Quinqueloculina* spp., *Robulus americanus*, *R.* spp., *et cetera*.

Lower Catahoula.—The basal division of the Catahoula is essentially equivalent to the sandy phase of the Frio or *Marginulina*-Frio section as recognized elsewhere. The top is placed at the top of the first sand or sandy shale below the *Marginulina* zone. As present around the Anse la Butte dome it is 800 to 1,200 feet thick, composed primarily of hard dark erratically fossiliferous shale with streaks of hard black sticky shale. From three to five thin zones of hard fine, in many places shaly, sand are present in this shale, corresponding with the ordinarily well developed *Marginulina* sands of other areas. At Anse la Butte the sands of this series do not aggregate more than 150 feet in total thickness and ordinarily much less.

In W. R. Davis' Voorhies wells on the east flank of the dome, rare *Marginulina howei* was encountered 500 feet below the top of the *Marginulina* zone. On the southwest side, in Glassell's T. Tortoris No. 1, this interval increases to 700 feet. On the north flank in the Stanolind's Nickerson No. 1, the *Marginulina mexicana* to *Marginulina howei* interval was only 150 feet. *Cibicides hazzardi*, ordinarily found in the shale interval above the fourth *Marginulina* sand in typical Louisiana Gulf Coastal fields, has been noted, but its occurrence here is too rare and erratic to give it notable value as a marker. Some favor the use of this foraminifer for determination of the upper limits of the underlying Chickasawhay.

Below *Marginulina howei* is a zone of hard gray shale in some places broken near the base by two sand bodies of thickness varying up to 50 feet. It seems likely that the lower of these sands is the producing sand in the Stanolind well on the far north side of the dome. Very rare specimens of *Marginulina texana* have been noted in two wells above these basal sands, but due to its rare and erratic appearance this species can not yet be used for correlation. This section includes about 300 feet on the east, but increases on the west and north flanks to at least 600 feet.

The variable length of intervals, and erratic appearance and development of sands in the lower Catahoula, are probably caused principally by faulting, although in part probably by changes in sedimentation. Since the foraminifera on which these intervals are based are rare, it may be that part of the discrepancy is due to errors of determination. The solution of this problem will require more data than are presently available from the few wells penetrating this section; the faunal assemblage and sequence here mentioned will doubtless require considerable revision as development progresses.

Chickasawhay Miocene (?).—No attempt is made here to establish definitely the age of the Chickasawhay, or its exact limits. Purely from the paleontological evidence, it seems to the writers that its rôle should be one of transition between the true Miocene of the Catahoula and the true Oligocene of the Vicksburg, since species characteristic of both are present in almost equal numbers. Hazzard, Blanpied, and Alexander (18; p. 7), as previously quoted, have suggested its Miocene age and subdivision into upper, lower, and Bucatunna members, with the latter lying unconformably on the Vicksburg (at the outcrop). Howe's preliminary studies (18; p. 15) of the paleontology described nearly the same number of species associated with the lower Miocene, as with the Oligocene. However, he states that "the percentages show more reason for assigning the Chickasawhay members to the Lower Miocene than . . . to the Oligocene." As only two wells at Anse la Butte have reached this formation, and none penetrated it to the true Vicksburg, the evidence is insufficient for subdivision, or even thorough discussion, at present.

The Chickasawhay is apparently a marine wedge represented updip by a less marine facies, so that within 15 or 20 miles the lower Catahoula apparently rests unconformably on the Vicksburg, with none of the typical Chickasawhay fauna remaining. There is also evidence that similar change in ecological and sedimentary conditions occurs westward along the coastal plain.

Garrett (7; p. 313) is "inclined to believe that the Hackberry assemblage is equivalent in part to the Chickasawhay beds, but that it reflects a very different environment" from that present at the outcrop. He also states that it is "definitely of younger age than Vicksburg." At Anse la Butte the Hackberry faunal assemblage is present close to the top of the Chickasawhay in moderate numbers, and has been employed by the writers as the criterion for determining the upper limit of the formation. This fauna becomes increasingly abundant in both species and individuals with depth. *Nonion lunatum*, *Gyroidina scalata*, *Pseudoglandulina comatula*, *Uvigerina stephensoni*, and *Bolivina mexicana* with rare *Nodosaria blanpiedi* are the typical markers, accompanied by many of the overlying *Marginulina* associates as well as *Pyrgo subsphaerica*, *Bulimina sculptilis*, *Saracenaria italica*, *Uvigerina* spp., *Angulogerina* sp., and *Operculinella* sp., the latter group being suggestive of the Vicksburg.

Pre-Miocene formations.—No formations older than Miocene have been penetrated *in situ* at Anse la Butte. Harris referred the light-colored clay exposed on the surface of the "butte" to the Oligocene because of its lithologic appearance, but Howe and Moresi (14; p. 76) found this material non-fossiliferous and of indeterminate age. Little was known of the subsurface strata from the wells drilled prior to 1940, since the value of micro-paleontologic studies was not appreciated, and little coring conducted from which lithologic and macro-paleontologic determinations might have been made.

The only material demonstrably older than Miocene was described by Howe and Moresi (14; p. 80) from a core taken at a depth of 1,500 feet in the Humble

Oil and Refining Company's Begnaud No. 6, just west of Flat Lake. It is described as "a hard fossiliferous sand dotted with abundant green specks of glauconite" and contained "a number of well-preserved Jackson fossils." The writers believe this may be a fragment of the Moody Branch marl member of the basal Jackson Eocene, carried up on the top of the salt core from its normal position. This would require an uplift for this sample of at least 10,000 feet.

Cap rock.—Many of the logs of wells drilled on the top of the Anse la Butte dome record streaks of "broken cap-rock" or "gypsum" for several hundred feet above salt and "hard cap-rock" in juxtaposition to the salt mass itself. Logan (16; p. 111) and others (19; p. 46) listed a part of the early production as coming from "cap-rock."

In detailed examination of cores and cuttings from numerous recently drilled wells, both super-salt and flank, the writers have found no trace of true cap rock or gypsum.[6] Material logged as "cap" in these wells, and probably in the older wells also, is very hard sandstone secondarily cemented with calcite, silica, or pyrite, and commonly containing oil in non-commercial form. It is possible that such indurated sandstones might be fractured above the apex of the salt core, and a simulated "cap-rock" production obtained from oil accumulated in these brecciated zones. Almost invariably wherever a sand was cored at its point of "pinch-out" with the salt, it was found to be highly mineralized and to contain at least a showing of oil. Such sands may produce oil in small quantities, depending on the degree of mineralization. These sands show a fair porosity on electrical logs and a high resistivity resembling that given by a normal oil accumulation.

No traces of sulphur have been reported.

Salt mass.—Cores of the salt plug from several wells have been described as consisting of firm coarsely crystalline halite. The salt commonly drills like firm sand, but "mushy" zones are logged. Cores from such zones seem to consist of individual halite crystals in a supersaturated brine, and probably represent solution cavities in the mass.

Several of the early shallow wells reported stringers of salt from a few feet up to several hundred feet in thickness, lying above the main salt mass. In several of these wells production was obtained below considerable thicknesses of supposed salt, leading to the belief by Fenneman (5), Harris (11), Howe and Moresi (14; p. 79), and others that Anse la Butte was an overhanging or mushroom-type dome. In the light of present evidence, including electrical logs, deviation records, and cored tops, it is questionable that there is any true overhang present. Minor lenses of salt may extend laterally for short distances from the sides of the salt plug, and pronounced irregularities such as bulges or depressions several hundred feet in size have been reliably determined. It is quite possible that early tests drilled with the equipment then available might have deviated at a con-

[6] F. W. Mueller, geologist for the Skelly Oil Company, noted a few inches of hard gray crystalline anhydrite and calcite lying immediately above the salt in the Skelly Oil Company's Republic Fee wells on the south flank of the dome.

siderable angle from the vertical, so that the well-bore would actually parallel the sides of the salt plug and, encountering protuberances from its surface, record them as "overhang."

Several wells drilled under the supervision of the writers encountered salt so unexpectedly shallow that it was thought it might be an overhang or a stringer above the main mass. Attempts were made to penetrate this salt, using a supersaturated brine solution instead of a normal fresh-water mud suspension for drilling fluid. Depths up to 500 feet into solid salt were attained.

In one such well, Glassell's Bendel No. 1, on the west flank, cuttings caught appeared to be pure rock salt but on solution were found to consist of about 5 to 15 per cent by volume of brittle gray shale, dense cream-colored limestone, and hard fine sandstone fragments. There was not a sufficient amount of such sediments in the cuttings to indicate their derivation from other than isolated fragments enclosed in the salt. Microscopic examination revealed this material to be derived from the *Heterostegina* zone, probably caught up from its normal position of about 9,000 feet or deeper and brought to its recorded depth of 4,891 feet by upward flowage of the salt mass.

PRODUCING SANDS

Sand bodies from very close to the surface down through most of the upper Catahoula have produced oil at Anse la Butte. No oil has been produced from the Marine Catahoula though several wells had showings in a sand in the *Discorbis* zone. Three wells have produced from sands in the base of the Catahoula or top Chickasawhay.

The producing area of each individual sand is ordinarily small and limited in peripheral location on the dome (Fig. 5). All producing sands deeper than the "stripper" group have been discovered and developed in the past few years. The stratigraphic position, approximate depth, and electrical characteristics of each sand are shown in the columnar sections (Figs. 3 and 4).

"Stripper" sands.—Under this group, have been arbitrarily included all producing sands from the surface down through the Moresi sand. The shallowest recorded production at Anse la Butte was at 400 feet in one of the wells drilled on the edge of Flat Lake in 1905, with an initial production of 40 to 50 barrels per day, open flow. Many other shallow wells were drilled in the immediate vicinity of Flat Lake, particularly on the northeast side. Most of these wells were small pumpers although the Lake Oil Company drilled three wells to about 1,850 feet which produced more than 1,700 barrels per day for some time and reported potentials up to 4,000 barrels per day. The age of these early producing sands and their lithologic characteristics can not now be determined, because of inadequate records. These sands are soft, thin, and erratic, and their exact water levels, structure, or areal extent can not be determined.

Recent drilling has established limited production in the base of the Pliocene (Deborah sand) at about 1,800 feet; and in the top of the Fleming Miocene (top

FIG. 5.—Flank producing areas at Anse la Butte.

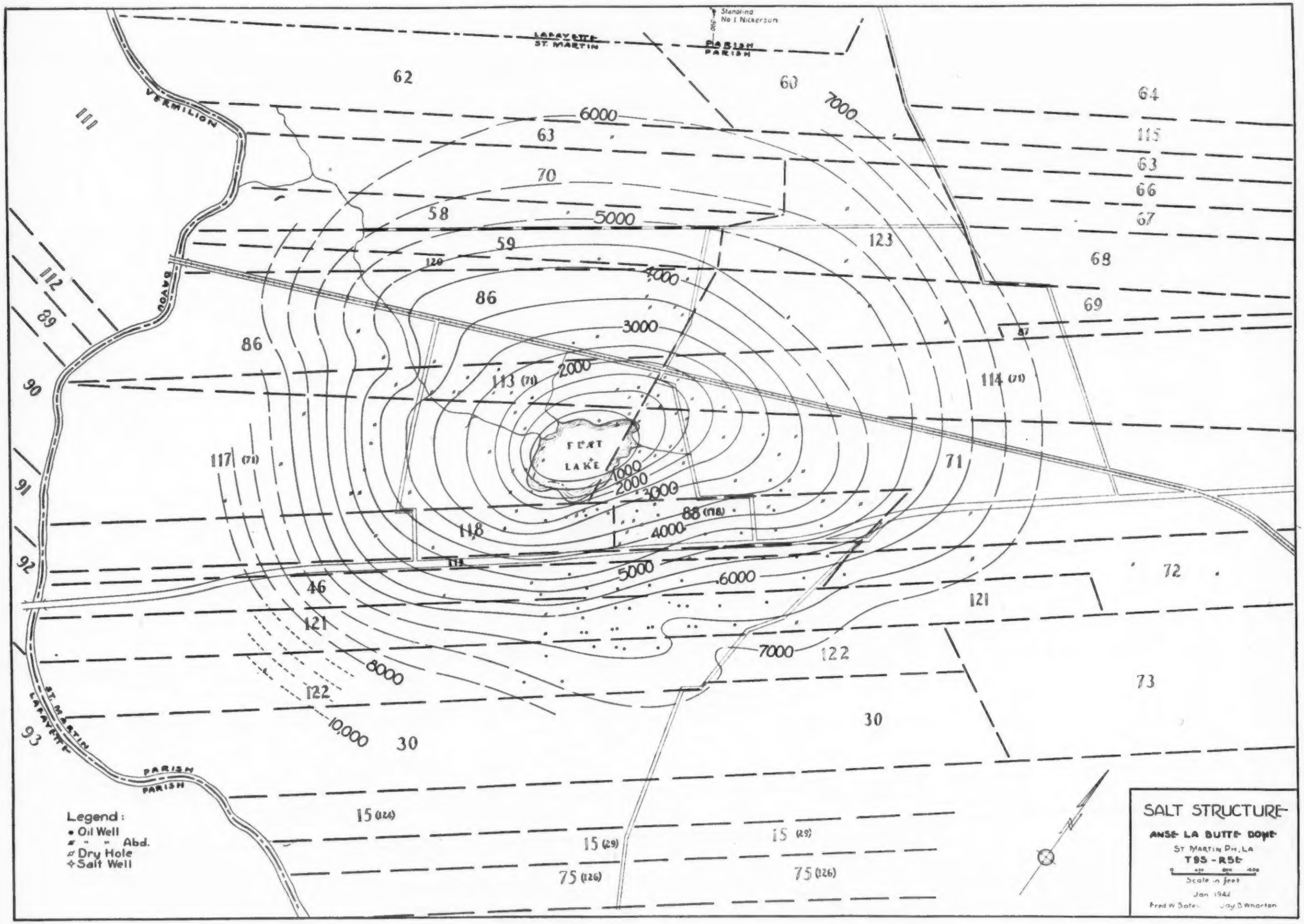


Fig. 6.—Structure-contour map of Anse la Butte dome drawn on top of salt mass.

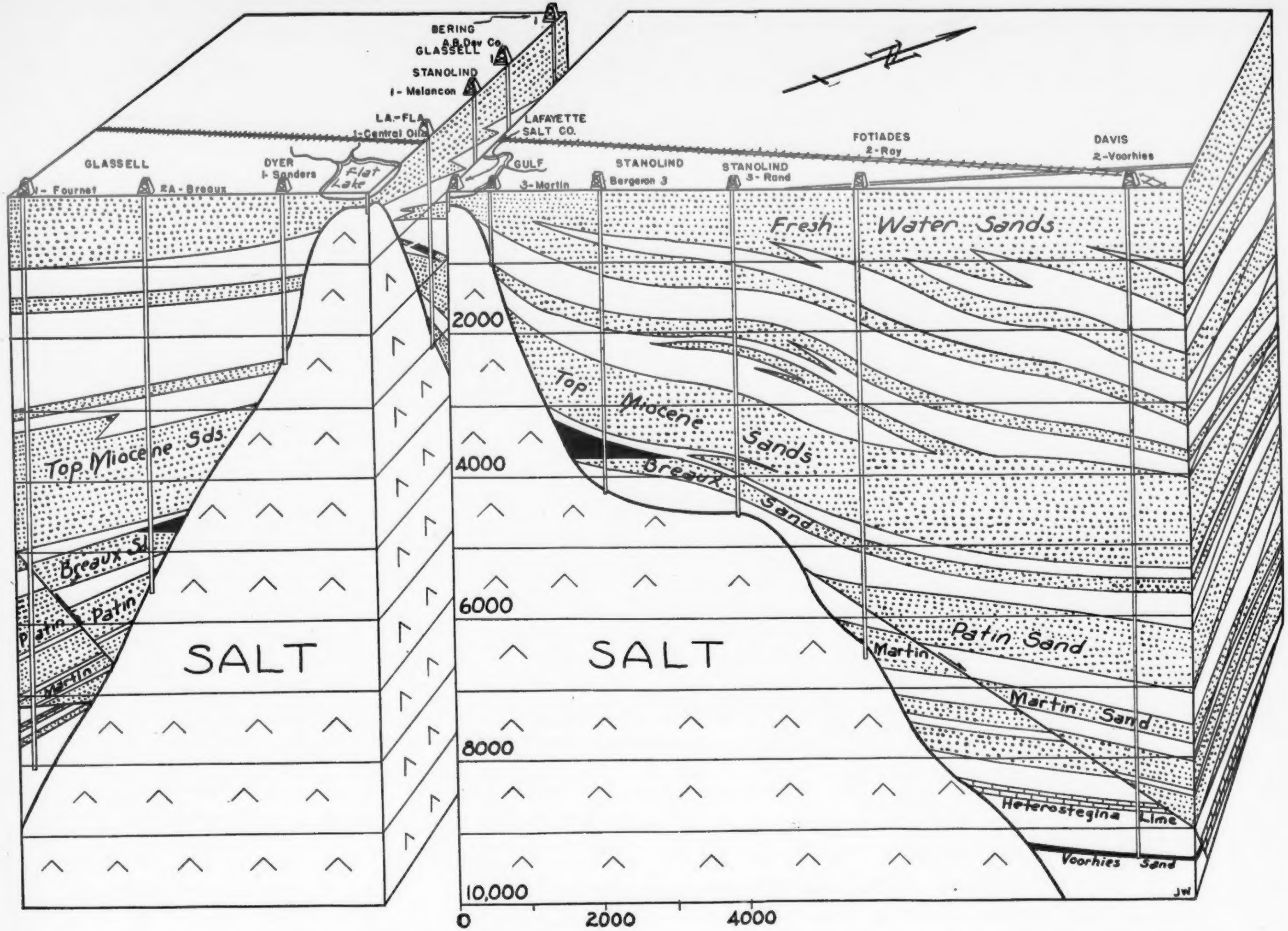


FIG. 7.—Block diagram of Anse la Butte dome looking northwest.

Miocene Sand series) between 2,000 and 2,500 feet, mostly on the south and southwest margin of Flat Lake. The Moresi sand or sands are found erratically within a few hundred feet above or below the *Potamides matsoni* zone, in wells drilled by the Iberia Petroleum Corporation on the Moresi lease adjacent to Flat Lake on the southeast.

Through August, 1942, the "stripper" production has totalled 1,262,833 barrels, from an estimated aggregate surficial area of about 50 acres.

Breaux series.—There are several producing sands found in the Fleming in addition to the ones noted in the "stripper" group. These are members of the lower part of the "top Miocene Sand series," closely allied in location, lithology, and production characteristics.

The Bergeron sand, about 100 feet thick, is encountered several hundred feet below the Moresi sand and 600 to 800 feet above the base of the Fleming. It produces oil in the Stanolind's L. D. Bergeron No. 1, but to date no other well has been completed in this sand. The productive area can not be much in excess of 5 acres, with an oil-water level at a depth of about 3,290 feet, and salt "pinch-out" at about 3,000 feet.

Another sand of this group is the true Breaux, varying from 150 to 400 feet in thickness in different parts of the field and occurring about 300 feet above the base Fleming. The discovery well for this sand, Glassell's Breaux Estate No. 1, also opened the current deep flank production, as previously described. The so-called "Patrick" sand of the southeast flank is now considered by the writers to be equivalent to the Breaux. A limited reserve is also present in the Breaux "A," a minor sand streak lying just above the main Breaux sand.

These Breaux sands are soft, fine, and highly permeable, with a water level at 4,675 feet on the southwest and 3,800 feet on the southeast. These two areas are separated by a barren strip and large faults. The Breaux-Patrick sand has a productive area of approximately 35 acres and produced 377,593 barrels of oil through August, 1942.

Patin sand.—The Patin sand is a firm, medium to coarse, porous sand 600 to 800 feet thick, yielding oil from above its water level of 4,800 feet up to about 4,200 feet where it pinches out against the salt mass. The lower Patin sand, a separate member, contains oil in the Stanolind's Emilie and Edmond Bergeron unit No. 1; it is believed that this sand constitutes a considerable reserve after depletion and deepening of existing Patin sand wells in this vicinity.

The Patin sand is one of the major producing sands of the Anse la Butte flank at present, having yielded 1,587,717 barrels of oil as of August 31, 1942, a little more than 2 years after discovery, from an area of about 110 acres.

Martin series.—A series of clean, permeable medium-grained sands with interspersed shale breaks extends from the base of the Patin sand down to the top of the Marine Catahoula, an interval of about 1,500 to 2,000 feet. Each sand in the upper half of this interval has been found saturated where located at the proper structural level, and it is possible that all may eventually be productive.

FIG. 7.—Block diagram of Anse la Butte dome looking northwest.

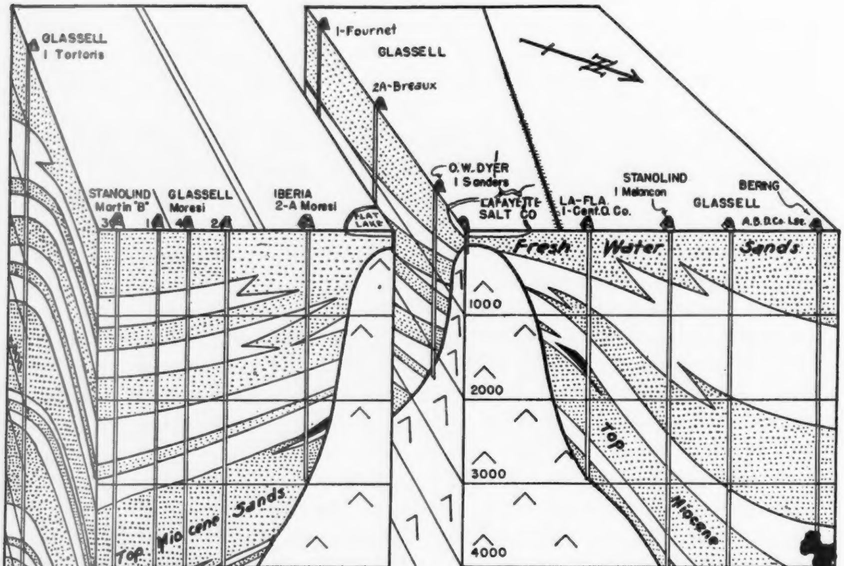


FIG. 8.—Block diagram of Anse la Butte dome looking southwest.

Immediately below the Patin is the Castille sand, about 60 feet thick in its best development, but ordinarily much thinner and very shaly. Oil accumulation in this sand appears to be governed by sand conditions or minor faulting rather than structural position. The minor quantity of oil so far produced from this sand has been included with that from the Martin sands. Below the Castille is a series of three sands all of which contain oil in limited areas. The first of these is the Unit sand, containing oil in the Stanolind's Emilie and Edmond Bergeron Unit No. 1. No wells now produce from this sand, though development will probably show accumulation under several locations.

The next two deeper sands (or more correctly, closely related groups of sands) are designated upper and lower Martin, having been first noted in the Stanolind's Martin No. B-2 and No. B-3 wells in April and June, 1941. These two groups aggregate more than 300 feet of effective sand with each series having a separate, independent water level. All members of each series are productive from the point of their pinch-out against salt down to their water levels at depths of 6,130 and 6,425 feet, respectively. They constitute a large part of the proved Anse la Butte reserve, with an aggregate production of 908,021 barrels through August, 1942. One or more members of this series have been observed to contain oil under a total of about 115 acres.

The remainder of the lower part of the upper Catahoula has several large sand bodies which may contain oil where found in favorable structural position. Thus far, in the large southeast fault block, every upper Catahoula sand from the Bergeron sand down has been found to contain oil where encountered close to its pinch-out against the salt.

Marine Catahoula.—Since this is a section in which shale and limestone predominate, it offers little chance for production. A fine tight shaly sand about 20 feet in thickness in the top of the *Discorbis* zone has been noted to contain oil or gas, but no production has been obtained to date.

Lower Catahoula.—The *Marginulina* sand series has been very disappointing at Anse la Butte. All of the tests drilled to this section have shown several erratic shaly sands containing oil or gas, but nothing which compares with the fine reservoirs available at this level in other coastal fields. Glassell's Fournet No. 1 and Tortoris No. 1 on the southwest, and the W. R. Davis wells on the southeast flank have cored sands with fair oil saturations, but, probably due to lack of permeability or lateral drainage area, commercial production has not yet been obtained.

Sands at the base of the lower Catahoula show considerably better physical characteristics and, together with those immediately underlying, will be the probable objective of future flank drilling. One of these was the sand recently tested by the Stanolind Oil and Gas Company in its Nickerson No. 1 on the north flank, which gave an initial potential of 310 barrels on a 9/64-inch choke, from a 60-foot sand section. Insufficient data are available to estimate the possible value or areal extent of production from this sand.

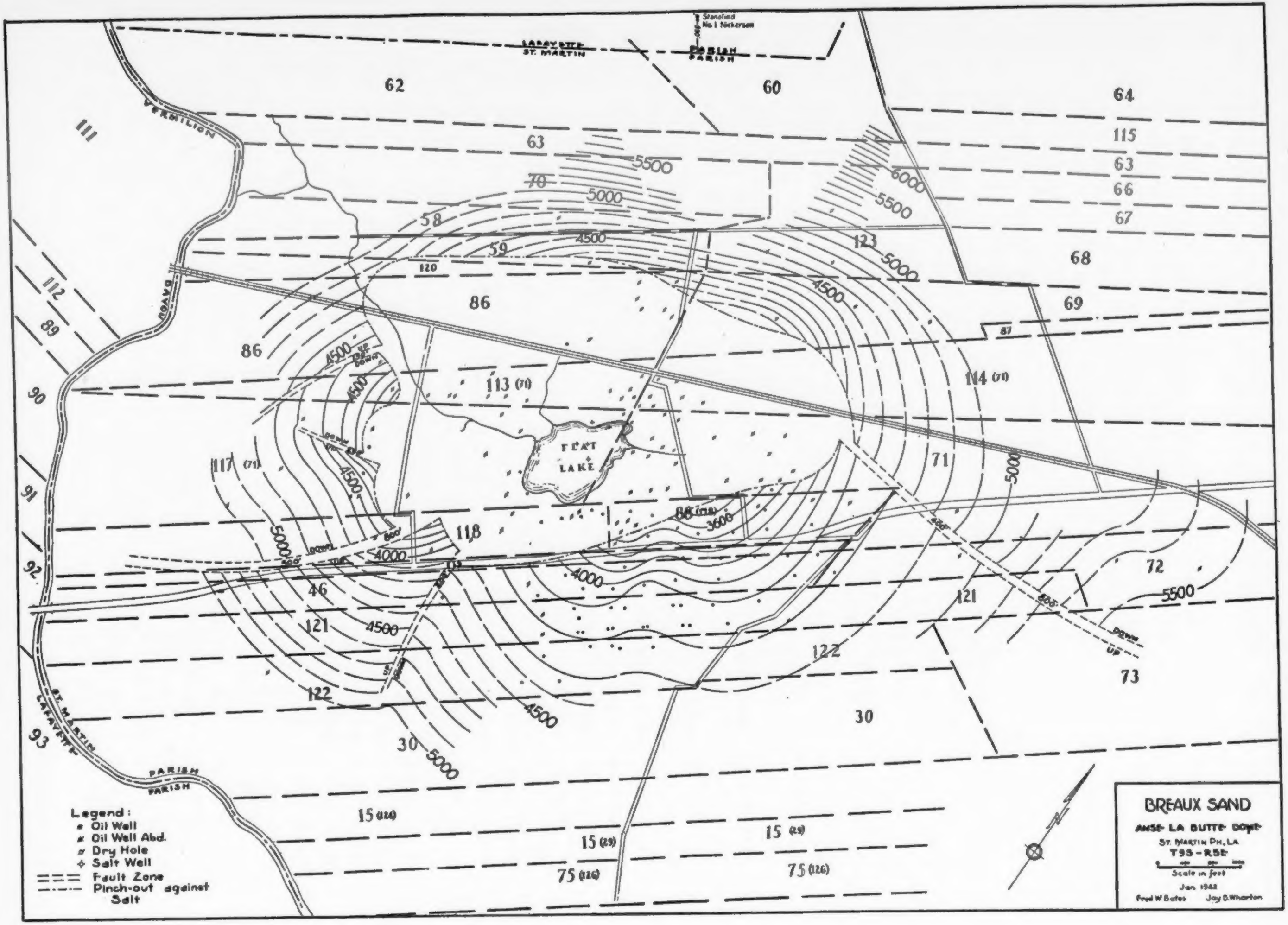


FIG. 9.—Structure-contour map of Anse la Butte dome drawn on top of Breaux producing sand.

Chickasawhay.—Several sands of fair permeability and thickness have been logged in the top of this zone on the southeast flank. In June, 1941, W. R.Davis completed Voorhies No. 2 in one of these sands, the well producing 51,560 barrels through January, 1942. Production ceased at this time and to date all attempts to recomplete have failed. A saturated sand apparently equivalent to the productive sand in No. 2 was tested in Voorhies No. 3 but also failed after producing oil for several days.

The early failure or total absence of production in tests of the lower Catahoula and Chickasawhay may be due to one or a combination of several causes. First, adequate lateral drainage may be impeded by low permeability and the condition aggravated by local shattering of the consolidated sands because of their proximity to the upthrusting salt mass. Second, the reservoir may be broken into many isolated segments by complex major faulting. Third, there is considerable evidence that these were the original reservoir sands on the dome, but that the oil has since escaped, wholly or in part, to the prolific shallower flank sands by way of the numerous fault zones. Wells in untested parts of the flank or farther removed from the salt plug may encounter conditions more favorable for accumulation and commercial production.

STRUCTURE

Anse la Butte is a piercement-type salt dome, with the highest part of the salt mass rising to within 160 feet of the surface. The dome centers under Flat Lake on the northeast end of Sec. 117, T. 9 S., R. 5 E. As shown in Figure 6, it is slightly elliptical in outline with the elongate axis trending northeast-southwest. The salt surface drops off steeply down to its 2,000-foot contour at which depth its longer diameter is about 3,000 feet, giving a rate of dip of 150 feet per hundred to this depth. Below this level, flattening or nosing is apparent toward the west and northeast, so that the 5,000-foot contour presents an asymmetric outline whose axial diameter is about 8,500 feet in length, with dips in the 2,000- to 5,000-foot interval much smaller and erratic. Dips toward the southeast remain steep, about 100 feet per hundred, down to 6,000 feet, below which a small irregular terrace is noted. No datum points are available below 7,000 feet, but it may be reasonably assumed that the surface of the salt mass becomes increasingly steep from this point down to its depth of origin.

It is interesting to note that the contours of the southeast surface of the plug are comparatively straight or slightly concave with a regular dip so that this face approximates a plane. About 95 per cent of the present reserve at Anse la Butte is trapped in sands truncated by this plane surface.

The block diagrams (Figs. 7 and 8) present a graphic true-scale three-dimensional picture of the configuration of the salt mass and its relationship to the adjacent sediments. A study of the attitude of the stratigraphic units suggests a history of intrusion of a relatively slender plug or spine, followed by spreading apart and tilting of formations by growth of the salt mass, rather than upward

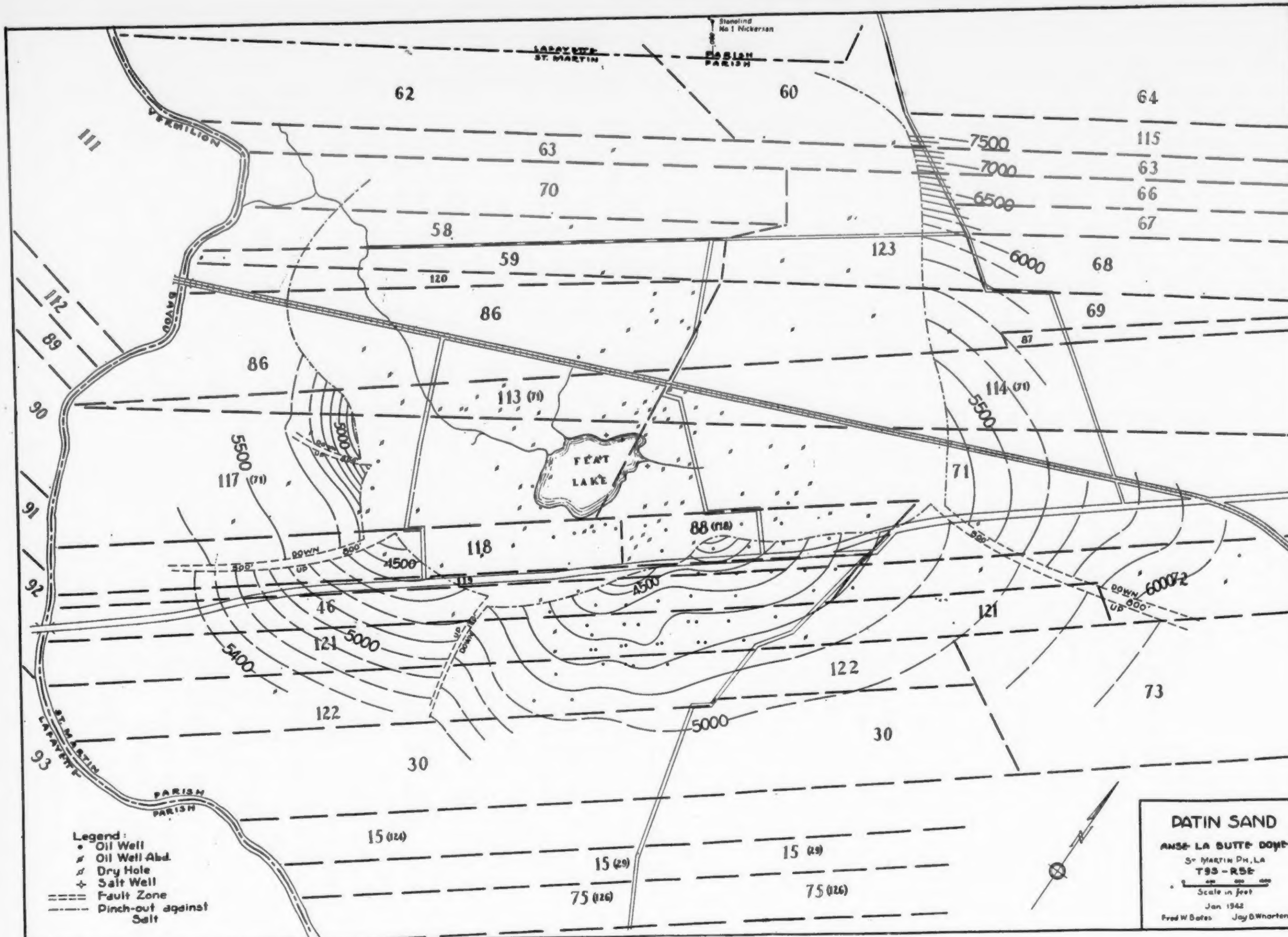


FIG. 10.—Structure-contour map of Anse la Butte dome drawn on top of Patin producing sand.

movement of a larger mass with deformation and uplift of older strata upon the top of the plug. It will be noted that none of the older formations is present, in recognizable form at least, on top of the salt mass, and that there has been relatively little uplift or erosion of the recent formations present there.

As previously discussed the writers have found no evidence of overhanging salt, despite its recognition in earlier literature. A study of the directional surveys of recent flank wells reveals a large and unpredictable variation in the inclination of the well-bore from the vertical, so that any attempt to map on datum points placed at the surface location of the wells will result in an erroneous interpretation. For this reason the maps and figures of this report are based only on the more recent wells from which both electrical logs and directional surveys are available. In dealing with dips as steep as those found at Anse la Butte, a slight deviation from the vertical results in a considerable change in the depth to any datum. The salt overhang previously recorded is probably due to the intersection of protuberances from the sides of the salt mass, by wells so inclined that they nearly parallel this surface.

The intrusion of salt has resulted in the formation of wedge-shaped blocks of sediments separated by major radial faults, following much the same failure pattern as results from the penetration of a sheet of tin by a bullet. Five of these faults, varying in size from 150 feet to 900 feet in displacement, are shown on the accompanying maps. Electrical logs have revealed the presence of other major faults and innumerable minor ones. Faults here are difficult to identify and to map because of the inconstancy of stratigraphic intervals and the lateral variation in sand conditions within short distances.

The accumulation of oil seems to be controlled to considerable extent by this radial faulting, certain of the blocks being highly productive and others totally barren. All of the deep wells have encountered extreme faulting in the Marine and lower Catahoula, as shown by the great variation in the recorded lengths of paleontologic intervals, and the erratic presence of sand bodies. Sidetracked holes, directionally drilled from several of these deep wells, have demonstrated the complete disappearance or appearance of major sand bodies within a few feet laterally. The faults appear to be composed of a group of parallel or *en échelon* faults within a zone several hundred feet in width, rather than confined to a single plane. Variations in direction of strike, in degree of dip, and in amount of displacement are noted in short distances both vertically and laterally, making exact identification or interpretation difficult or impossible.

Although the presence of many more faults is recognized, use of the few shown has permitted reasonable and regular structural contouring of different horizons. The control is insufficient to determine whether the fault planes displace part of the salt mass or die out at its surface.

To give a clear picture of the structural conditions encountered in Anse la Butte, four contour maps have been prepared. One of these is on the top of the salt with a contour interval of 500 feet (Fig. 6). The three sand maps show the

FIG. 10.—Structure-contour map of Anse la Butte dome drawn on top of Patin producing sand.

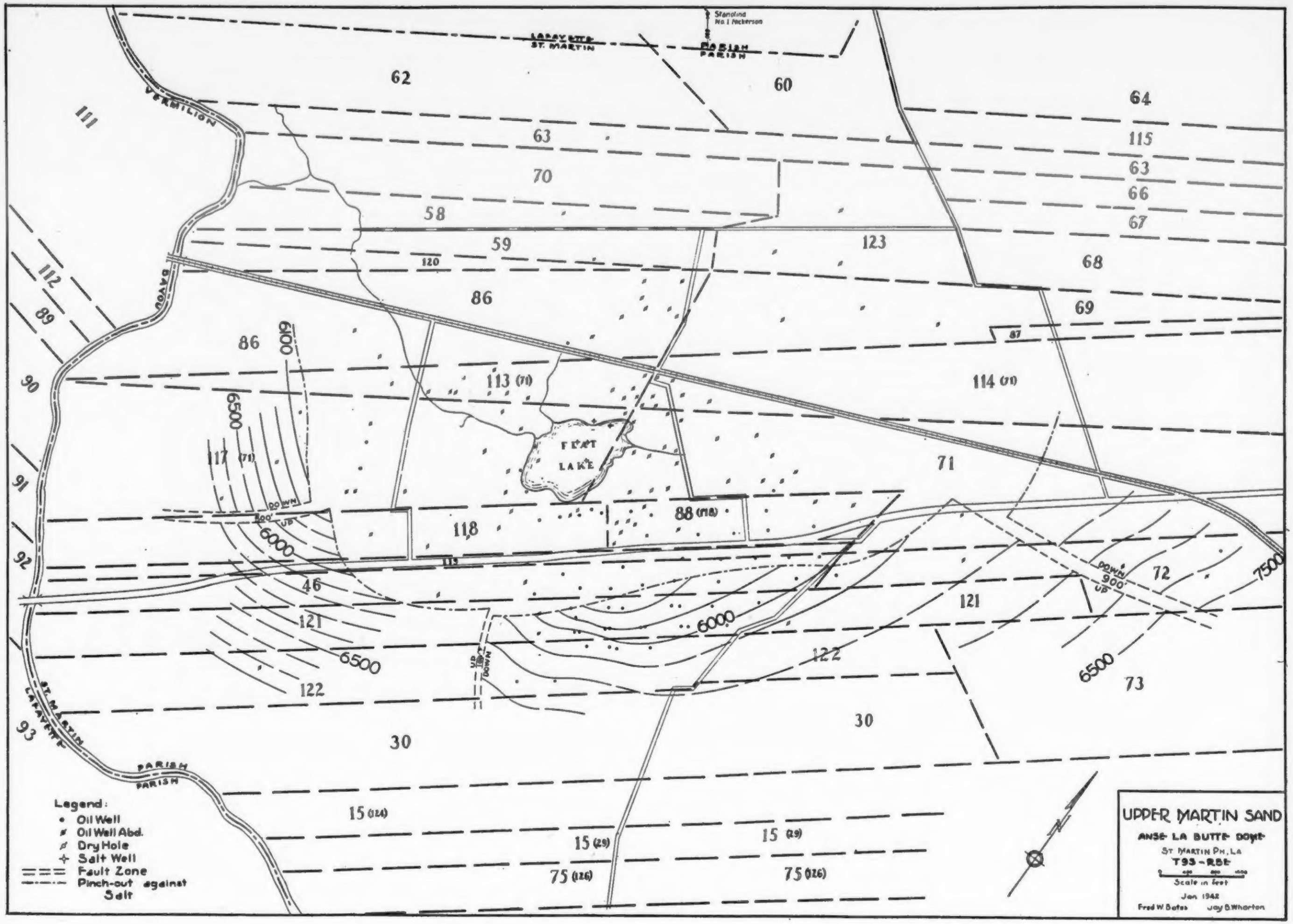


Fig. 11.—Structure-contour map of Anse la Butte dome drawn on top of upper Martin sand.

structure and position of the Breaux, Patin, and upper Martin oil sands in relation to the salt, using 100-foot contour intervals. Maps of a sand truncated by salt intrusion show not only the structure of that sand, but also the trace of the intersection of the upper surface of the sand with the salt. The sand is nowhere present up-structure from this "pinch-out" line.

More datum points are available for the Breaux sand map (Fig. 9), drawn on the shallowest of the sands, since many wells did not reach the deeper levels. Control is best on the southwest and southeast where most of the recent wells are located; consequently, most of the mapped faults are in this area. There is probably as much faulting around the remaining periphery of the dome but the control is inadequate to determine it. The means employed for representation of faults shows the area within which the top of the sand is missing, by two more or less parallel lines, the distance between them being proportional to the fault displacement. If it is assumed that the fault has a 45° dip, the scaled distance between the two limiting lines is approximately equal to the displacement; with increase in the angle of dip, the width of the fault zone decreases. The Anse la Butte faults are all normal and vary between 50° and 65° in dip from the horizontal.

On the north and northwest sides of the dome the Breaux sand and the shale below it form a very thin layer over the salt. The Patin sand, about 400 feet deeper than Breaux, is present in very few wells on this north side of the dome, most of the tests going almost immediately into salt after penetrating Breaux sand.

On the Patin sand map (Fig. 10) a probable "pinch-out" line has been drawn, showing that on the north the Catahoula is present only on the extreme flank, near the edge of these maps. North flank dips are so steep that production from sands of the upper Catahoula, if present at all, will be found to form a very narrow band. As deep control is imperfect on the north side of the dome, no attempt was made to show the possible attitude or location of the deeper Martin sand in this area (Fig. 11).

The similarity of the structure of the three sands on the south side of the dome is broken only by the shifting of the fault traces toward the downthrown block and the progressive outward movement of the "pinch-out" with increasing depth. Changes in the attitude of the sands are minor. It can be said in general of the flank sands that they are truncated by and tilted against the salt at rather steep angles on the south, become increasingly steep on the north flank, and are broken into radial segments by several large normal faults. Some of these fault blocks contain oil; others do not. The reason for this selective accumulation is not apparent at present, but undetected tangential or concentric faults may be the factors controlling migration of oil from off-structure into the several blocks.

No attempt has been made to map formations deeper than the upper Catahoula. The Voorhies and Nickerson sands are the only indications of the presence of commercial deep oil sands to date. As these two areas are approximately 120°

apart around the dome, it may be found that deep oil sands circle the larger part of the Anse la Butte dome.

ESTIMATE OF RESERVES

The artificial control of rates of production at Anse la Butte and the frequent completion of wells in only one of a series of multiple oil sands precludes the use of any graphic maximum-capacity, production-decline, or pressure-decline curves for computation of ultimate recovery. Since few wells have cored their entire producing section, there are no data from which estimates based on the degree of saturation of the reservoir could be made.

In several key wells, however, the producing sections were completely cored and analyzed under the supervision of the writers. From the data thus secured on permeability, porosity, percentage of oil saturation, gas and connate water content, and other factors, the anticipated ultimate recovery per acre-foot of effective saturated sand can be calculated. Because of the steep dips and accumulation of the oil in highly permeable continuous reservoirs, it seems likely that the water drive will be almost perfect under the rates of production now used, resulting in drainage by natural flow of a high percentage of the recoverable oil. The small drop in reservoir pressures and regular encroachment of water levels demonstrate this expectation as reasonable.

TABLE II

ESTIMATED ULTIMATE RECOVERY FROM ANSE LA BUTTE DOME

Sand	*Prod. Acreage*	*Avg. Sand Thickness (Feet)*	*Est. Ult. Recovery (Barrels)*	*Production to Sept. 1, 1942*	*Remaining Reserve (Barrels)*
Stripper	50	36	1,800,000	1,262,833	537,167
Bergeron	5	40	200,000	75,960	124,040
Breaux	35	50	1,750,000	377,593	1,322,407
Patin	110	100	11,000,000	1,587,717	9,412,283
Martin	115	150	17,250,000	908,021	16,341,979
Total	315		32,000,000	4,212,124*	27,787,876

* Does not include production from the Hackberry series, for which the reserve can not yet be calculated.

A recovery of 1,200 to 1,400 barrels per acre-foot from the upper Catahoula sands, and 1,000 to 1,200 barrels per acre-foot from those shallower in the section, is indicated. For the figures given in Table II on total ultimate recovery from each sand, a figure of 1,000 barrels per acre-foot of effective sand has been used. By comparison with actual recoveries (4; p. 53) from flank sands of similar nature and depth, now approaching depletion on other piercement-type domes, this figure seems conservative.

The acre-feet of saturated effective oil sand in each sand was calculated by first determining the volume of the irregular reservoir bounded at the base by the water level, above by the upper surface of the sand, and up the structure by the truncating surface of the salt mass. These dimensions can be accurately determined since electrical logs and directional surveys are available for each

well. A suitable factor was applied to compensate for any shale breaks or zones of decreased permeability known to exist, and the total original ultimate recovery computed, using the 1,000-barrel per acre-foot factor.

Table II suggests a total original ultimate reserve for the field of 32,000,000 barrels of oil from 315 acres, or more than 100,000 barrels to the acre. Since 4,212,124 barrels have been produced through August, 1942, a remaining reserve of 27,787,876 barrels is indicated. These figures include neither the reserves nor production from any sands deeper than upper Catahoula.

SUMMARY AND CONCLUSION

Anse la Butte has seen two distinct periods of active development. The first phase involved shallow super-salt and flank production, the discovery of which, early in the century, was attributable to surface indications such as elevation, gas seeps, and so forth. After 40 years of intermittent exploratory drilling, flagging interest in the area was revived by the discovery of deeper flank production. Subsurface well data, comparison with deep flank accumulation around similar domes, and geophysical exploration provided impetus for the phase of deeper development, increasing the total proved reserve to more than 30 million barrels of oil under about 300 acres.

About a half million barrels of the original 2 million-barrel reserve in the shallow "stripper" sands still remains. The deeper flank area is now apparently completely developed, though some additional accumulation at these depths may yet be discovered. Although not comparable in volume with the anticipated ultimate recovery from the flanks of such piercement-type domes as Jennings, Anse la Butte is nevertheless an important source from which many years of profitable production are indicated.

A third cycle of development may follow for this field, since recent testing of formations still deeper on the flanks suggests that sands in the Marine and lower Catahoula may offer a considerable reserve. However, the problems presented will be so entirely different from those of the two preceding phases, that the writers feel they may best be left for consideration at a later date. The limited knowledge of the deeper strata permits no reasonable prediction of their ultimate value, though the preceding pages have included all pertinent data so far available.

It is hoped that this discussion may be of some aid both in the eventual solution of the many remaining geological problems at Anse la Butte, and in development of the flank reserves of other piercement-type domes.

ACKNOWLEDGMENTS

The writers express their appreciation to Glassell and Glassell, the Stanolind Oil and Gas Company, and other operators in the field, for permission to publish the data secured from their wells, surveys, and other records. Sincere thanks are due Max Bornhauser for his suggestions in dealing with geological problems as

they arose during the development of the field, and his counsel and criticism in the preparation of this paper. Many other geologists and individuals have been of great help in analysis of the geological and paleontological problems and their presentation herein. To Katharine Bates for her patience and help in preparing and criticizing this paper, the writers are deeply grateful.

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REVIEWS AND NEW PUBLICATIONS

STRUCTURAL GEOLOGY, BY MARLAND P. BILLINGS

REVIEW BY A. J. EARDLEY[1]
Ann Arbor, Michigan

Structural Geology, by Marland P. Billings. 473 pp., 19 pls., 336 figs. Prentice-Hall, 70 Fifth Avenue, New York (1942). Price, $4.50.

The writer has used Professor Billings' new textbook in structural geology for 2 semesters and finds it remarkably well suited to his own undergraduate course and well liked by the students. Through a questionnaire about 2 years ago it was learned that the widest imaginable variations in courses in structural geology exist throughout the United States, and equally varied notions are prevalent as to what a textbook in structural geology should include and to whom it should be addressed. Also, since the reviewer was not sure that the existing American texts defined, limited, and expounded structural geology satisfactorily, he awaited with interest Professor Billings' book.

There appear to be three phases of structural geology: (1) principles, methods, and techniques; (2), the structural elements of the continents; and (3) geotectonics. Emphasis in Billings' book has been placed on the first. The structure of specific areas is discussed briefly, for the purpose of illustrating principles. Billings states in the preface that he has intentionally refrained from a treatment of the more speculative phases of geotectonics because he believes that such subjects can be intelligently studied only by geologists with a broad background in many fields of geology.

The best résumé of the mechanical principles of structural geology yet written for the undergraduate is given in the first 26 pages. Some parts of succeeding chapters refer to these pages but it is not inconvenient to assign them later on if desired. It is, however, the definite intention of the author to discuss the mechanics and origins of the structures as he goes along with their descriptions. For instance, besides the introductory pages on mechanics, there are Chapter 5, "Mechanics and Causes of Folding," and Chapter 6, "Failure by Rupture."

Another chapter that brings up to date and presents very clearly and without bias the subject matter is "Secondary Foliation and Lineation." The reviewer has assigned the pages on secondary foliation but not on secondary lineation because his students are generally not far enough along (most of them are taking lithology concurrently with structure and have had no field experience), but the whole chapter is excellent for a graduate student to review.

Individual chapters on unconformities and salt domes follow folds, joints, faults, and foliation. Igneous rocks are then discussed very ably in the light of modern research under three chapters, "Plutons," "Granite Tectonics," and "Extrusive Igneous Rocks." These chapters bring to the student an adequate, authoritative, and balanced picture of the shapes, sizes, and structures of igneous rocks. Some instructors in the oil states will not care to consider the igneous as thoroughly as Billings does.

The next to the last chapter is on "Structural Petrology." The reviewer has not taken up this chapter in the basic course because the material is covered in other courses at Michigan and because it is, in his opinion, of graduate character. It is a pleasure, however, to have such a readable and understandable summary of the subject at hand.

The last chapter is on "Geophysical Methods in Structural Geology." Gravitational,

[1] Department of geology, University of Michigan. Manuscript received, June 9, 1943.

magnetic, seismic, and electric methods are briefly but clearly described and illustrated. It is Billings' thought that information gained from geophysical methods has now come to supplement visible geology so importantly that the interpretation of geophysical data has become part of the domain of the structural geologist. About 45 pages are devoted to the subject. This chapter may be very valuable to instructors in departments where no geophysics is taught, and this may be the principal reason for its insertion. In departments where a separate course in geophysics is taught, the subject probably will not be taken up in the course in structural geology.

The last of the very fine features in the book is the "Laboratory Exercises." Any instructor may feel that his course has been highly successful if the students have done the exercises and worked the problems that are here presented. The method of solution of the problem or of use of the diagram is first given, then practical exercises and problems are listed. Some of the exercises are set up on tear-out pages. The various groups of exercises are listed as follows: thickness and depth of strata, outcrop pattern of horizontal and vertical strata, patterns of dipping strata; three-point problems, structure sections of folded strata, geometric reconstruction of folds, structure contours and isopachs, trigonometric solution of fault problems, projections, solutions of three-point and fault problems by descriptive geometry, and unconformities, faults, and folds.

From the foregoing it may be seen that such subjects as isostasy, geosynclines, and the theories of mountain building, familiar in our other texts in structural geology, are not treated. The reviewer believes that problems and exercises are far more important in the basic course in structural geology than extended reading, that the average student is poorly prepared to understand, or appreciate, the theoretical discussions of geotectonics, and that time is not available in a 3-hour semester course for problems and geotectonics both. He, therefore, heartily approves of Billings' choice of subject matter. The book sets a good standard according to which all undergraduate courses could profitably be adapted within the limitations, of course, that many varying conditions in different institutions impose.

Billings proposes a few new symbols or variations of more or less standard symbols to show the attitude of the axis and axial plane of a fold, and platy and linear structure.

The book is specifically a college text and is not a handbook or a reference book.

PENNSYLVANIAN SYSTEM IN NEW MEXICO, BY M. L. THOMPSON

REVIEW BY R. V. HOLLINGSWORTH[1]
Midland, Texas

"Pennsylvanian System in New Mexico," by M. L. Thompson. *New Mexico Bur. Mines Bull. 17* (1942). 92 pp., including index, table of contents, list of illustrations and tables, 8 figs., and 2 pls. Socorro, New Mexico. Price $0.50.

For more than 30 years the name Magdalena has been used to designate all strata of Pennsylvanian age in New Mexico and no detailed studies of the system preceded this one. Thompson's report, which is preliminary, deals specifically with the Pennsylvanian section where these beds crop out in central New Mexico. The outlying and more isolated outcrops were not investigated. The sequence consists of predominantly marine strata and is subdivided into four series: Derry, a new name for an incomplete Atoka age section, and the three Mid-Continent series Des Moines, Missouri, and Virgil, with which well

[1] Exploration department, Shell Oil Company, Inc. Manuscript received, June 24, 1943.

established correlations are made. Each series comprises two groups, and 16 formations are defined and new names applied to them. The subdivision and classification of the rock units is based on detailed studies of lithological and paleontological data obtained during several seasons of field work. Type localities are designated and graphic type sections with descriptions are presented for each of the units investigated.

The writer is to be commended for the extensive use made of the foraminiferal family Fusulinidae, the highly important Pennsylvanian and Permian index fossils. This complex group of biologically simple forms exemplifies a complete and subdivisible evolutionary series and thus furnishes the basis for micropaleontological criteria for correlations which are rapidly replacing those based on paleobotanical evidence from the Upper Carboniferous and Permian strata.

The three well established Mid-Continent series names were wisely extended into this area as a result of the fusulinid studies. The reviewer believes, however, that introduction of the new term "Derry series" for a relatively incomplete section of Atoka age strata was not justified in view of the well established correlation based on fusulinids which are identical with forms from the Atoka formation and the Marble Falls limestone. Had the designation Atoka been applied to this incomplete sequence the continuity of Mid-Continent series terminology would have been preserved. This would serve to clarify, rather than confuse, the already cumbersome Pennsylvanian terminology.

The concept set forth in the preceding paragraph is supported by the fact that the Pennsylvanian section in New Mexico consists predominantly of marine limestones and is remarkably similar to that in the much studied, classic Mid-Continent area. Similar, but less striking, comparisons can be made with the more clastic Pennsylvanian strata in north-central Texas.

The defined subdivisions comprise lithological and paleontological units which are recognizable throughout extensive areas in central New Mexico from the Nacimiento Mountains southward into the Hueco and Franklin mountains. The recent discovery of petroleum and natural gas reserves in rocks of Lower Pennsylvanian age in San Juan County, northwestern New Mexico, emphasizes the need for such investigations as this one of the Pennsylvanian rocks in the state.

Graphic sections consistently reproduced on a scale readily adapted to the standard well-log scale of one inch equals 100 feet are a boon to the petroleum geologist and the author's practice in this matter will be found very convenient. Microstratigraphers who study the Pennsylvanian strata in New Mexico may share the reviewer's opinion that the descriptions which accompany the measured sections in many papers on stratigraphy are not sufficient to meet present requirements of detailed subsurface work and will hope that additional details are to be included in Thompson's final report. Such data as texture, lithologic accessories, characteristics of cherts, *et cetera*, are important criteria for regional as well as local correlations in many instances.

Two preoccupied formational names were inadvertently used but they are to be replaced in the final report.[2] The name Hot Springs, applied to an Atoka age (Derry series) formation, was applied to a sandstone of Carboniferous age in the Ouachita Mountains by Purdue in 1910 and the name Armendaris, used for the lower group of the Des Moines series, was given to a limestone of Lower Ordovician age in northern New Mexico by Keyes in 1915.

The writer accomplished his purpose of establishing a basis for a detailed classification of the Pennsylvanian system in New Mexico very successfully and this contribution should rank as a pioneer work on the stratigraphy of the state.

[2] Written communication, April 3, 1943.

AERIAL PHOTOGRAPHS AND THEIR APPLICATIONS, BY H. T. U. SMITH

REVIEW BY LOUIS DESJARDINS[1]
Edmonton, Alberta, Canada

Aerial Photographs and Their Applications, by H. T. U. Smith, assistant professor of geology, University of Kansas. 372 pp. D. Appleton-Century Company, Inc., New York (1943). The Century Earth Science Series, edited by Kirtley F. Mather. 6.25 ×9.25 inches. Price, $3.75.

Geologists, teachers, students, laymen, photogrammetrists, specialists all, will find here the best book on aerial photographs yet to appear. The author has a gift for clear, careful writing, with not only a complete command over his subject matter and its organization, but over the problems likely to beset the minds of students approaching the subject. The specialist will find the reading truly a pleasure. The geologist will find the geological treatment so complete and so well presented and illustrated, that in spite of other non-geological subject matter, the book should become one of the most important contributions to geological literature of this or any other year. The book is free from sins both of commission and omission of previous books on aerial photographs, and in fact is so superior from every standpoint that it is truly the first of its kind. It is ideal as a text book, and it will permit new courses being introduced in schools and universities where there was none before. The book has a greater wealth of illustration than has yet appeared in any other popular or general book on aerial photographs. Particularly meritorious is the liberal use of stereoscopic illustrations enabling any reader who provides himself with two simple lenses, or even who practices the eye exercises included, to study these in three dimensions.

The underlying geometric and mathematical theories of photos as related to stereoscopy and maps (elementary photogrammetry) are well presented, free from any taint of borrowing or undigested rehashing of previous publications. The book covers a broad field with perfect balance. All these related aspects of the subject are of interest to the geologist.

In the introduction, Chapter I, a brief historical sketch shows that aerial photography is older than the airplane, the earliest experiments being made from balloons and kites. The progress of the science has been greatly stimulated by both World Wars, and by advances made over many years in the United States, Canada, and many foreign countries. Improvement in aerial cameras is also discussed, and the field of amateur aerial photography is not overlooked.

The second chapter, on the characteristics of aerial photographs, very clearly and intelligibly gives the reader the essential background of photogrammetry necessary to the understanding of the relations of aerial photographs to maps, and will familiarize him with the terms so frequently met in photogrammetric literature, as principal point, focal length, tilt, isocentre, parallax, *et cetera*. These characteristics, as they vary from vertical photographs, low obliques, and high obliques, are skillfully presented. The relations of both ground relief and tilt to the scale of the photograph are made readily understandable. All diagrams are adequate and clear, and the presentation includes much essential elementary information which the reviewer has not seen in any previously published work.

The chapter on stereoscopy, Chapter Three, after describing different types of instruments, gives such good instruction about acquiring or improving stereoscopic vision, that any reader with two eyes who has experienced difficulty in seeing stereoptically before will succeed now. Important theoretical considerations related to depth perception and stereoscopy not found in other publications are here presented.

[1] Aero-geologist, Post Office Box 129. Review received, July 3, 1943.

A distinct departure is Dr. Smith's careful separation of "general principles of interpretation," Chapter Four, basic to all proficiency in later interpretation, from specific types of photo interpretation. These general considerations include preparatory data such as scale determination, location and orientation, and time and date of photography, general criteria as color tone, form, size, shadows and shading, texture, association, pattern, and stereo relief, limiting factors as scale, sharpness of definition, contrast, and ratio of air base to flight altitude, miscellaneous markings of extraneous character, and lastly quantitative criteria relating to measurement of distance, direction, area, heights, elevation, and relation to maps and mapping.

Even after these general principles and conditions of interpretation have become familiar, the interpretation for special purposes will ordinarily require first a mastery of geographic and topographic content. Dr. Smith devotes Chapter Five to geographic and topographic interpretation, including in the former such features as roads, railroads, tunnels, bridges, air fields, water transportation, telephone lines, power lines, pipe lines, buildings, excavations, quarries, mines, oil and gas wells, drill holes, rural and agricultural features, terracing, strip farming, orchards, cultivated land, pastures, irrigated land, urban features, residential and business districts of towns, parks, and features relating to city growth and population. Topographic features treated include bedrock, loose rock, sand, soil, vegetation of many types, snow, also streams, determination of direction of flow, channel characteristics, channel shifting, drainage patterns, ponds, lakes, swamps, springs, *et cetera.* The positive elements of topography come in for detail treatment, and a classified outline for the whole is given.

Chapter Six deals with making planimetric maps from vertical photos, and Chapter Seven from oblique photos. In Chapter Six, some of the topics are index maps, uncorrected planimetric maps from single photos and from sets of photos, and corrected planimetric maps, by which is meant "reducing or eliminating the effects of parallactic displacement due to topographic relief; compensating for differences in the scale of different photos in the set used; effecting greater accuracy in the orientation of photos with respect to one another; checking the accuracy of the assembly by reference to ground points at intervals; and avoiding the distortion introduced by tilt." This treatment includes ground control, picture-point control by radial-line intersections and three methods of using these, namely, the ruled-template method, the overlay method, and the slotted-template method. The chapter concludes with the compilation of detail and other methods, also hydrographic charts, and map revision from vertical photos.

The Chapter on obliques gives a full exposition of perspective grids, and other useful information original with the author. Chapter Eight is on photomosaics and Chapter Nine on contour maps from aerial photos. The latter subject is classified and treated under methods of stereo sketching, plane-table methods, simple contouring instruments, complex contouring machines. Thence oblique photos in contour mapping, and stereo contour maps.

Chapters Ten and Eleven are on geologic interpretation and physiographic interpretation, respectively, and together constitute more than 100 pages. In the first of these, general criteria and limitations are carefully set forth. The first section on lithologic interpretation treats of sedimentary rocks, both consolidated and unconsolidated, igneous rock bodies of all types and metamorphics. The section on structural interpretation also establishes criteria and treats of dip, strike, joints, faults, recent faults, folds, and unconformities.

Next a section on geologic mapping discusses techniques of revision of pre-existing maps, extending mapping from areas already mapped, mapping in unknown territories and preparation for field study. Relation to field mapping and field check are fully discussed. Structural contouring methods are presented. Finally the subject of using aerial photos in the study of dynamic geology is considered.

In the Chapter on physiographic interpretation the basis for any study of physiography is presented in clearer terms than the reviewer has seen discussed in any other connection by any writer. The general order of study is guided by these factors: "influence of lithology and structure on topography, if any; dominant process in shaping the present topography; other processes, past or present; climatic implications of processes; evidences, if any, as to initial form; and erosional and depositional chronology." Whereas "it is in the field of physiographic or geomorphic interpretation that aerial photographs offer the broadest opportunity" (p. 265), limitations include scales, forest covers, obliteration of natural features by the work of man, inadequate data on slope and elevation, morphologic ambiguity, and limitations of present knowledge of form. The chapter proceeds with descriptions and examples of landforms of volcanic and tectonic origin, land forms produced by mass movement, landforms of eluvio-fluvial erosion cycle, glacial ice and glacial topography, land forms produced by subsurface solution, coastal topography, and land forms of eolian origin. Next is physiographic mapping and a discussion of aerial photos in the study of physiographic processes.

The book concludes with Chapter Twelve on aerial photographs in economic geology, engineering, and other fields, treating of mining geology, petroleum geology, engineering geology, general engineering, forestry, agriculture, city and regional planning and archeology, and Chapter Thirteen on military applications, treating of military aerial photography, military mapping, military intelligence, and military geology and physiography.

Each Chapter in the book contains a well selected bibliography and a set of exercises or problems for students. Appendices at the end of the book include a glossary of photogrammetric terms, information on the selection and procurement of aerial photos, twelve suggested study sets, with necessary photos, supplementary maps and literature, the use and handling of photos, and a complete series of laboratory exercises.

Criticisms.—This reviewer offers the following points for the benefit of those engaging in a careful study of the book.

P. 17. I am glad to see approval of name "Aero-geology" for this field.

Bot. p. 28. This determination of scale presupposes that the reader is familiar with scale expressed as a fraction of map distance to corresponding distance in nature.

P. 31. It should be noted that 60 per cent overlap in area is also 60 per cent along the line of flight.

Mid. p. 43. Tilt here blamed too much on pilot. Photographer, not pilot, is responsible for tilt.

P. 55 (end first paragraph). The author has independently discovered a source of three-dimensional illusion which the reviewer has made a subject of extensive investigation! (*ms.* now in preparation).

bot. p. 67. It should be noted that magnifying glasses commonly give power in terms of areas, not diameters, for example, power of 4 diameters would be marked 16×.

Mid. p. 70. This reviewer agrees with preference for lens-type stereoscope to mirror-type for routine use.

No. 2, Bot. p. 79. Ink annotations do not detract from stereoscopic effectiveness except for minute details covered by ink lines themselves.

P. 82 (Fig. 25). I suggest these diagrams be turned upside down to agree with direction seen from the eye.

P. 113 (ref. to Pl. 9E). Features found in lower left side of plate.

P. 115. All references to Pl. 11 should be Plate 12.

P. 143. Errors in indentation noted.

P. 147. Author has failed to include photographic index maps.

P. 149, bot., and p. 150, top. Here is the first serious mistake yet found in the book. The method of tracing here described simply will not work, no matter how "normal" one's eyes are! You can not keep the photo image from wandering about!

P. 153. No. 5 should include enlargement and reduction by photostat.

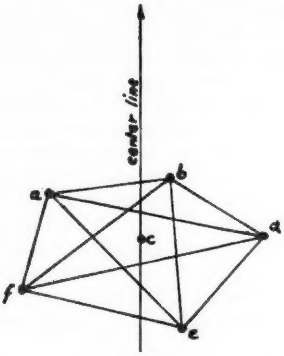
P. 154. No. 2. Lens stereoscope is just as good as, or better than, mirror stereoscopes for transferring centers. Furthermore, for this step, there is no need for careful orientation of prints. (Quick, approximate orientation merely to get fusion is sufficient.) The author goes out of his way to make transfer of center points seem difficult.

P. 166, mid. In connection with the author's description of use of three control points in one

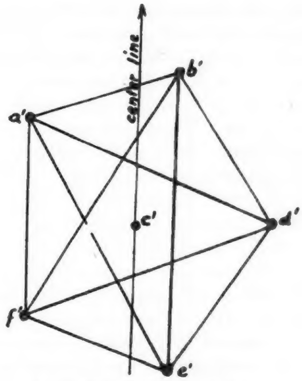
overlap area, it must be noted that there is a simple method requiring only two control points, and these need not even be in the same overlap area.

P. 169, mid. "In using the overlay method, radial-lines are first drawn on the photos." The only radials that need be drawn on the photos are the two resected, starting with the third print.

P. 188, bot. Would expect much more difference in appearance between *A* and *B* in Figure 46 if tilt angle is 35°. Here is my check up of this figure (assuming *B* to be correct, and assuming center point at *c*, and center line, as shown.)



A. Photo, center at *c*, axis tilted 35°.



B. Map. Traced from Smith's Fig. 46, p. 188.

P. 191, top, Fig. 47. Very intriguing and apparently correct. Will the author kindly prove it?

P. 200, top. In connection, the author should also include the case of contouring on photo guided by contours on a pre-existing topographic map.

Mid. p. 200. In this connection the author should also mention the important field of physiographic control of horizontality.

Bot. p. 203. The stereometer does *not* measure parallax difference! (The author later makes the subject quite clear.)

Top p. 205. Would be better to read: "Will cause contours as drawn by floating mark to depart," *et cetera.*

Top p. 209. Does not really mean B.M., but merely any point of known elevation.

Upper p. 210. There is a special case of tilt with no change of *y* direction. Statement that "adjustments in *y* direction may be necessitated by displacements due to relief" is not true, as *y* components are always equal.

Bottom p. 261. This reviewer thought that his method of contouring on opposite photos from those containing annotated geology and estimating elevations along beds *stereoscopically* was well known. Its mention would belong here.

Bottom p. 295. Reference to Pl. 24 refers to stereo inset.

Ch. 11. Chapter 11 has no mention of mounds, especially pimple mounds. Suggestion that the text should include a heading "Miscellaneous," to include this, Carolina Bays, and other interesting forms not treated.

MICROMERITICS, THE TECHNOLOGY OF FINE PARTICLES, BY J. M. DALLAVALLE

REVIEW BY W. C. KRUMBEIN[1]
Washington, D.C.

Micromeritics, the Technology of Fine Particles, by J. M. Dallavalle. 1st ed. (1943). 428 pp., illus. Pitman Publishing Corporation, New York, N. Y. Price, $8.50.

This volume brings together a considerable amount of information on the properties

[1] Senior geologist, Beach Erosion Board, War Department. Review received, July 8, 1943.

and behavior of small particles. Emphasis is placed on methods of measuring particles and on their physical and chemical behavior. For the science of small particles the author proposes the term "micromeritics" from the Greek, meaning "small parts."

The outstanding feature of the book, in the reviewer's opinion, is the author's inclusion of several topics usually omitted or organized less explicitly in similar texts on sediments more familiar to geologists. These topics include a discussion of the dynamics, the thermodynamics, and the chemical behavior of small particles, as well as their electrical, optical, and sonic properties. The chapter on dynamics, for example, reviews dimensional analysis and introduces the concepts of the Reynolds and Froude numbers; it includes material on the behavior of particles in fluids (Stokes law *et cetera*); and it discusses the equations of motion as they apply to the particles. The thermodynamic chapter includes the theory of heat conduction in packings, and the flow of heat through granular materials. The chapter on chemical behavior includes the solubility of small particles, crystal growth and granulation, and oxidation phenomena among small particles. The chapter on electrical, optical, and sonic properties includes a discussion of electrical conductivity, diffusion and scattering of light, and sonic flocculation of particles. Workers with sediments interested in the chemical and physical principles underlying certain aspects of sediment behavior will find these chapters stimulating, as well as a chapter on the transport of particles, in which are discussed the several theories of bed-load and suspended sediment transportation. These latter are treated mainly from the engineering point of view, rather than as theoretical hydrodynamic phenomena.

In addition to these several chapters on what may be considered the dynamics and energy aspects of particles, considerable space is devoted to the characteristics of packings, to the flow of fluids through granular media, and to infiltration and capillarity. The chapter on the characteristics of packings is of considerable interest because of the importance of packing phenomena in the behavior of oil-field fluids. Several subjects of specialized interest, such as muds and slurries, the theory of fine grinding, and atmospheric and industrial dusts, are included in the book as applications to particular fields.

The reviewer's emphasis on the foregoing material does not mean that the author neglected the laboratory aspects of small particles. Throughout the book emphasis is placed on techniques of measurement, such as particle-size study, shape measurement, and particle surface. Much space is devoted to the determination of the size distribution, both by sieving and sedimentation methods, and the calculation of statistial parameters is described in detail. For the most part the methods and discussion follow engineering and physical literature, with comparatively little representation of the large contributions from geology.

Practicing oil men, both production engineers and geologists, will find the volume rich in suggestions which may be either directly applied or which may be translated into petroleum terms. The specialist on sediments will welcome the volume for its sources of information on topics not generally considered by workers in sedimentary petrology. The style of the book is clear, and no attempt was made to avoid mathematical language where it is needed. The book is a welcome addition to its field, and for geologists is valuable in giving an insight into the contributions engineering has made to the subject of small particles.

REVIEW OF PETROLEUM GEOLOGY IN 1942, BY F. M. VAN TUYL ET AL.

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

"Review of Petroleum Geology in 1942," by F. M. Van Tuyl and members of the Departments of Geology, Geophysics, and Petroleum Engineering of the Colorado School of

[1] Amerada Petroleum Corporation. Review received, July 21, 1943.

Mines. *Colorado School of Mines Quarterly*, Vol. 38, No. 3 (July, 1943). 75 pp. Price, $1.00.

As an expansion of the service to petroleum geology of the research committee of the American Association of Petroleum Geologists, an annual review of important developments in this and allied fields was inaugurated in 1942 and the first report was presented at the Fort Worth convention of the Association. The review was prepared by the combined geological, geophysical, and petroleum engineering staffs of the Colorado School of Mines and was presented by Dr. F. M. Van Tuyl. It has now been published as the July, 1943, number of the *Quarterly* of the Colorado School of Mines.

This complete summary of activities covers a survey of the literature of geology and a canvass of 160 informed persons in the profession. A bibliography of 209 titles, reviewed in the text, gives an idea of the thoroughness with which the literature was covered.

Section heads are titled as follows: Important Events of the Year, Advances in Petroleum Geology and Allied Subjects, Aerial Photographs, Miscellaneous New and Improved Techniques, Noteworthy Discoveries (of petroleum deposits), Contributions of Petroleum Geology to Pure Geology, Production and Reserves, Trends in Petroleum Geology and Geophysics. Under these headings mention is made of practically every discovery, development, and scientific contribution which affected petroleum geology in 1942. The 55 pages of text are crammed with information which is invaluable to everyone working in petroleum geology or associated fields.

A critical study of the paper reveals the inevitable unevenness which accompanies a report prepared by many collaborators, but this failing leans more toward too much information on one topic rather than too little on others. Undoubtedly, the succeeding reviews will benefit from this excellent beginning and will assume a greater polish as the years go by. Certainly, this and subsequent reviews should be an important part of the library of everyone interested in petroleum geology for they will serve as a ready reference to the important activities in the profession.

The research committee of the Association is to be complimented on securing the hearty coöperation of the Colorado School of Mines in its publication program. This is the second report published for the committee. The first report, entitled "The Time of Origin and Accumulation of Petroleum," by F. M. Van Tuyl and Ben H. Parker was published as the April, 1941, number of the *Quarterly*, as a comprehensive summary of the present opinion on this important phase of petroleum geology.

RECENT PUBLICATIONS

ARKANSAS

*"Unitized Pressure Maintenance, Jones Sand Reservoir, Shuler Field, Arkansas," by George R. Elliott. *Oil and Gas Jour.*, Vol. 42, No. 5 (Tulsa, June 10, 1943), pp. 53–60; 65; 7 figs.

CALIFORNIA

*"Greeley Oil Field," by Furman H. Updike. *California Oil Fields*, Vol. 27 (San Francisco, 1943), pp. 5–8; 3 pls.

*"Rio Bravo Oil Field," by Fred E. Kasline. *Ibid.*, pp. 9–12; 4 pls.

*"Rincon Oil Field," by Wm. C. Bailey. *Ibid.*, pp. 13–17; 5 pls.

*"Geologic Formations and Economic Development of the Oil and Gas Fields of California," prepared under the direction of Olaf P. Jenkins. *California Dept. Nat. Res. Div. Mines Geologic Branch, Bull. 118* (Ferry Building, San Francisco, April, 1943). Published in 4 parts, including outline geologic map showing oil and gas fields and drilled areas: Pt. 1, "Development of the Industry"; Pt. 2, "Geology of California and the Occurrence of Oil and Gas"; Pt. 3, "Descriptions of Individual Oil and Gas Fields"; Pt. 4

"Glossaries, Bibliography, and Index, including Outline Geologic Map" (scale 1 = 1,000,000). Pts. 1 and 2 are separately bound in paper and Pts. 3 and 4 are bound together in paper. 8.5×11 inches. 773 pp., 375 illus. Price, $4.00. Final cloth-bound volume, $6.00 (when ready). Separate copies of the Outline Geologic Map, $1.00.

GENERAL

*_Aerial Photographs and Their Applications_, by H. T. U. Smith. 372 pp., 62 pls., 51 figs. The Century Earth Science Series. D. Appleton-Century Company, 35 West 32d Street, New York (1943). Price, $3.75.

Fightin' Oil, by Harold L. Ickes. 174 pp., illus. "The inside story of the relationship between our petroleum supply and the state of global war told by the man charged with the responsibility of delivering oil on time to the battle lines and the home front." Alfred A. Knopf, 501 Madison Avenue, New York (1943). Price, $1.75, net.

*"Classification of Sedimentary Rocks Related to Kind of Oil Reservoir," by W. V. Howard. _Oil and Gas Jour._, Vol. 42, No. 4 (June 3, 1943), pp. 70–71, 90.

*"Lithification Processes and Early Oil Formation in Sediments." _Ibid._, No. 6 (June 17), pp. 92–94; 3 figs.

*"Oil Zones of the United States: Pennsylvanian," compiled by _Oil and Gas Jour._, Vol. 42, No. 5 (Tulsa, June 10, 1943). 2 pp. between pp. 64 and 65, with map in colors.

*"Oil Zones of the United States: Permian." _Ibid._, No. 8 (July 1). 2 pp. between pp. 48 and 49.

*"Evolution and Classification of Paleozoic Crinoids," by Raymond C. Moore and Lowell R. Laudon. _Geol. Soc. America Spec. Paper 46_ (New York, June 15, 1943). 153 pp., 13 pls., 18 figs.

*"Bacteria as Geological Agents with Particular Reference to Petroleum," by Claude E. ZoBell. _Petrol. World_, Vol. 46, No. 6 (Los Angeles, June, 1943), pp. 30–43; 2 photographs.

*"The Universal Stage (with Five Axes of Rotation)," by R. C. Emmons. _Geol. Soc. America Mem. 8_ (New York, March, 1943). 205 pp., 13 pls., 95 figs.

*"Mesozoic and Cenozoic Arcidae from the Pacific Slope of North America," by Phillip W. Reinhart. _Ibid., Spec. Paper 47._ 117 pp., 15 pls., 3 figs. 3 tables.

*"Factors Influencing Declining Oil-Discovery Rates," by L. F. McCollum. _Oil Weekly_, Vol. 110, No. 4 (Houston, June 28, 1943), pp. 18–22; 4 charts.

*"Significance of Secondary Recovery in the United States," by Paul D. Torrey. _Oil Weekly_, Vol. 110, No. 3 (June 21, 1943), pp. 18–28.

*"Secondary Recovery in Terms of the Engineering Problem," by George H. Fancher. _Ibid._ (June 28), pp. 24–31.

*"Factors Necessary for Consideration in Planning a Secondary-Recovery Development," by R. C. Earlougher. _Ibid._ (July 5), pp. 19–32; 12 figs.

*"Flowing Water-Flood Production," by T. F. Lawry. _Ibid._ (July 12), pp. 46–50; 2 figs.

*"Transcontinental Gravitational and Magnetic Profile of North America and Its Relation to Geologic Structure," by George Prior Woollard. _Bull. Geol. Soc. America_, Vol. 54, No. 6 (New York, June 1, 1943); pp. 747–90; 9 pls., 6 figs.

KANSAS

"Analyses of Crude Oil from Some Fields in Kansas," by E. C. Lane and E. L. Garton. _U. S. Bur. Mines R. I. 3688_ (April, 1943). 95 pp., Free.

*"Exploration for Oil and Gas in Western Kansas during 1942," by Walter A. Ver Wiebe. _Kansas Geol. Survey Bull. 48_ (Lawrence, June, 1943). 88 pp., 30 figs.; 31 tables.

NEW JERSEY

*"Geologic Correlation of Areal Gravitational and Magnetic Studies in New Jersey and Vicinity," by George Prior Woollard. *Bull. Geol. Soc. America*, Vol. 54, No. 6 (New York, June 1, 1943), pp. 791–818; 5 pls., 2 figs.

TEXAS

"Analyses of Crude Oils from Some Fields of Texas," by E. C. Lane. *U. S. Bur. Mines R. I. 3699* (May, 1943). 2 pp., 50 tables. Supplements *Tech. Paper 607* (1939). Free.

TURKEY

*"Geology and Mineral Deposits of the Erzinean Region," by V. Stchepinsky. *Publications Inst. Etudes et Recherches Minieres de Turquie*, Ser. C, Mon. 2 (Ankara, 1941). 103 pp., 5 pls., geologic map in colors. In Turkish and French.

*"Geology of the Petroliferous Part of the Bassin de Boyabat (Vilayet de Sinop)," by Maurice M. Blumenthal. *Ibid.*, Ser. A, Communication 6 (1942). 63 pp., 5 figs., 2 photographs. Pp. 1–36 in Turkish; pp. 37–63 in French.

*"Contribution to the Study of the Cretaceous Fauna of Turkey," by V. Stchepinsky. *Ibid.*, Ser. B, Mem. 7 (1942). 68 pp., 7 pls., sketch map. Pp. 1–33 in Turkish; pp. 34–68 in French.

*"Paleontological Study of Some Lias Beds of Anatolie," by Galib Otkun. *Ibid.*, Ser. B, Mem. 8 (1942). 41 pp., 4 pls., 7 figs., sketch map. In French.

*"Geological Notes on the Area between Boyabat and Ekineren (Vilayet Sinop, Northern Turkey), by I. Ortynski and S. W. Tromp. *Maden Tetkik ve Arama Enst. Mecmuasi*, Sene 7, Sayi 3/28 (Ankara, 1942), pp. 399–12 in Turkish; pp. 412–24 in English; map, section, and chart.

VIRGINIA

*"Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia," by Byron N. Cooper and Chilton E. Prouty. *Bull. Geol. Soc. America*, Vol. 54, No. 6 (New York, June 1, 1943), pp. 819–86; 5 pls., 3 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Volume 13, No. 2 (August, 1943).

"Use of the Microprojector in the Mechanical Analysis of Small Samples of River Sand," by Richard G. Grassy.

"Graphic Representation of Chemical Weathering," by Parry Reiche.

"Shape and Roundness of Lake Erie Beach Sands," by F. J. Pettijohn and A. C. Lundahl.

"A Visual Method of Estimating Two-Dimensional Sphericity," by Gordon Rittenhouse.

**Journal of Paleontology* (Tulsa, Oklahoma), Volume 17, No. 4 (July, 1943).

"Cardinal Process of Productidae," by A. H. Sutton and Charles H. Summerson.

"Upper Cretaceous Foraminifera from Northwestern Peru," by Don L. Frizzell.

"Pleistocene and Pliocene Ostracoda of the Coastal Region of Southern California," by L. W. LeRoy.

"Ordovician Conodont Faunas from Oklahoma," by E. B. Branson and M. G. Mehl.

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1940," by Hans E. Thalmann.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27 NO. 8 (AUGUST, 1943), P 1168

THE ASSOCIATION ROUND TABLE

ASSOCIATION COMMITTEES

The list of Association committees, with the names of the chairmen and the members, is published in the June *Bulletin*, pages 876–78.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Clark Goodman, Cambridge, Mass.
W. L. Whitehead, Roland F. Beers, A. I. Levorsen
Harry Alvah Sprague, Bakersfield, Calif.
Edward V. Winterer, Art R. May, Frank Ittner
Carlton Wesley Wheeler, Wichita Falls, Tex.
Lynn K. Lee, Karl A. Mygdal, Darsie A. Green

FOR ASSOCIATE MEMBERSHIP

Richard Frederick Cast, Lincoln, Neb.
E. F. Schramm, Eugene C. Reed, Oliver J. Scherer
Alan Richard Keevil, Calgary, Alta., Canada
J. M. Kirby, W. A. Findlay, Max Steineke
Robert Brading Morton, Evansville, Ind.
F. W. DeWolf, Harold R. Wanless, Harold W. Scott

FOR TRANSFER TO ACTIVE MEMBERSHIP

Edgar Ernest Rehn, Mt. Vernon, Ill.
E. P. Philbrick, F. E. Wimbish, W. A. Ver Wiebe
Gordon Wilbur Seren, Houston, Tex.
A. J. Childerhose, W. W. Patrick, Louis H. Morris

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 8 (AUGUST 1943), PP. 1169-1170

MEMORIAL

ROY A. REYNOLDS
(1889–1943)

Roy A. Reynolds died, June 19, 1943, at the Methodist Hospital, Fort Worth, Texas, after having been in ill health for several years. He had been afflicted with lukemia but the immediate cause of his death was a cerebral hemorrhage.

Roy was one of the earliest members of the American Association of Petroleum Geologists and had a host of friends. It is rare that a positive character, with so much accomplishment in his record, can enjoy the universal affection and approval of all who knew him. I have never known an acquaintance, associate or competitor to speak ill of him. All were admirers of his agreeable disposition and equable temperament. That, and his eminent standing as one of the leading reconnaissance geologists of his time, were his two outstanding characteristics. He was generally considered to have few equals and no superiors at surface mapping.

ROY A. REYNOLDS

He was born at Kansas City, Missouri, August 30, 1889, of second generation Scotch and English parentage, and spent most of his boyhood on a farm near Paola, Kansas. He remained close to the soil and a lover of the outdoors, which made him especially effective in dealing with farmer-landowners. He graduated from the Paola (Kansas) High School in 1907, taught school 4 years for funds to attend the University of Kansas and graduated in 1916 with a B.A. degree, majoring in geology. He was one of the organizers of Sigma Gamma Epsilon, the geological fraternity, at the University of Kansas, and later was instrumental in installing its chapter at the University of Oklahoma. He joined the staff of the Empire Gas and Fuel Company and spent 2 years with that company as a field geologist and then a district geologist, principally in North Texas, where he chanced to be located at the time of the Ranger Boom in 1918–1919.

In partnership with H. H. Adams, he was very active in consulting work in the Ranger area where, for the first time in petroleum exploration in the Mid-Continent, it was recognized that minor terracing and very faint swings in strike in the surface beds might point the way to oil accumulation. His acute perception of very low dips stood him in good stead during the Ranger play but he was equally outstanding when, a dozen years later, he was called upon to map quite unfamiliar beds, the Tertiaries of the "tortured Apennines" in Italy.

Following his consulting experience at Ranger he turned his attention to operating and, as general manager, directed the activities of several small producing companies in North Texas for several years. In 1925 to 1928 he was associated with J. Elmer Thomas in petroleum exploration and independent operating, principally in north-central Texas. The last 15 years of his life, except for a year spent in Europe with Thomas, he was a consulting geologist, appraiser, and manager of producing properties, including his own.

Roy was predominantly a family man and, unlike most field geologists and oil operators, he managed to spend a substantial portion of his time at his home in Fort Worth, where he located in 1925. Each year he spent a month or more with his family on a fishing and camping trip in the San Saba country and each fall he usually made at least one hunting trip to Old Mexico. He lived to see all three children grown up, through college, and happily employed, which must have been a great satisfaction to him in his last lingering illness. When in Europe in 1931, he had his entire family join him at Christmas time in Rome, and had the pleasure of showing them many interesting places in Italy, Germany, and France.

He is survived by his wife, Minnie Diediker Reynolds, whom he married in 1917, and three children, Lt. Bruce W. Reynolds, now at Camp Van Dorn, Mississippi, and twins, Lyle W. Reynolds, Flight Instructors School, Wichita Falls, Texas, and Louise Reynolds, now residing in Dallas. He is also survived by two brothers, O. W. Reynolds, of Big Lake, Texas, and J. A. Reynolds, of Paola, Kansas.

He was a charter member of the Fort Worth Geological Society and served as its president in 1937–1938. He was also very active in the Fort Worth Rotary Club and at the time of his death was president of its Educational Foundation. He was an excellent golfer and a member of the Colonial Country Club at Fort Worth.

The American Association of Petroleum Geologists, the geological fraternity, and the Fort Worth community have lost a most pleasant and valuable member.

J. Elmer Thomas

Fort Worth, Texas
July 6, 1943

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 8 (AUGUST, 1943), PP. 1171-1174

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

THEODORE A. LINK is chief geologist for Imperial Oil Limited "Canol Project" (a United States Government Project), address Box 129, Edmonton, Alberta. "Canol" is a 100 per cent war project in the Mackenzie River Basin, Northwest Territories, Canada. Link worked as field geologist in this area from 1919 to 1922, and located the discovery well at Norman Wells (50 miles north of Fort Norman) in 1919. The well blew into production in August, 1920.

HOWARD A. GIBSON, of Austin, Texas, is with Imperial Oil Limited, Norman Wells, N.W.T., Canada.

Major J. EARLE BROWN, formerly consulting geologist of Fort Worth, Texas, is executive officer of the Army Air Base at Alamogordo, New Mexico.

SILAS C. BROWN has resigned his position with the Kansas and the United States geological surveys. He is an ensign in the Armed Guard of the Navy.

Lieutenant (jg) E. T. HECK, of the West Virginia Geological Survey, is in the Armed Guard of the Navy.

FRANK N. BLANCHARD, JR., formerly with the Skelly Oil Company at Pampa, Texas, is with the Sinclair-Wyoming Oil Company at Jackson, Mississippi.

H. J. K. FICHTER, formerly with Cia. Petroleo Shell, Bogota, Colombia, is with the Caribbean Petroleum Company, Caracas, Venezuela.

J. G. WILSON, of The Texas Petroleum Company, has moved from Bogota, Colombia, to Apartado 267, Caracas, Venezuela.

FRED M. BULLARD, professor of geology and mineralogy at the University of Texas, is teaching courses in geology in the Summer School of the National University of Mexico, as a part of the coöperative project made possible by a grant from the Coördinator of Inter-American Affairs and sponsored by the Institute of Latin American Studies of the University of Texas. EZEQUIEL ORDONEZ, professor in the National University of Mexico, is collaborating with Bullard in a seminar on "Volcanoes."

JOSEPH M. PATTERSON, of The Texas Company, at San Antonio, Texas, has gone to The Texas Petroleum Company, Caracas, Venezuela.

R. B. WHEELER, of The Texas Petroleum Company, Bogota, Colombia, is now with The Texas Company, New Orleans, Louisiana.

WALTER K. LINK, of the West India Oil Company, has left San Jose, Costa Rica, and is stationed at Havana, Cuba.

H. W. MCDONNOLD, formerly with The Texas Company, is with the Keystone Exploration Company, Houston, Texas.

ARTHUR L. BOWSHER is a second lieutenant in the Corps of Engineers. He may be addressed: EORP-EUTC-B-OSS, Camp Claiborne, Louisiana.

W. G. WOOLNOUGH, honorary member of the Association, has been appointed superintendent of the bibliographical and editorial section, Technical Practice Directorate, Ministry of Munitions. His address is 340 Collins Street, Melbourne, Australia.

G. E. MANGER has been transferred from Venezuela to Houston, Texas, with the Gulf Oil Corporation.

Lieutenant JOHN WALTER REISS, of Corpus Christi, Texas, was killed in the European Theatre of Operations on June 4, according to information sent by the War Department to his mother, Mrs. Estelle E. Reiss, 1810 Santa Fe Street, Corpus Christi, Texas.

H. E. HEATER, formerly at Pittsburgh, is with the Standard Oil Company of California, 225 Bush Street, San Francisco, California.

ARCHIE R. KAUTZ, formerly district geologist for the Cities Service Gas Company at Amarillo, Texas, is now chief geologist with the company and is stationed at Bartlesville.

HARRY L. BALDWIN has returned to the United States after an absence of 4 years with Yacimientos Petroliferes Fiscales in Argentina.

New officers of the Amarillo, Texas, Geological Society are: president, JOHN S. VAN SANT, J. M. Huber Corporation; vice-president, A. B. VAN TINE, Gulf Oil Corporation; secretary-treasurer, CARY R. WAGNER, JR., Pure Oil Company.

NORMAN S. HINCHEY, formerly with the Shell Oil Company, Inc., is assistant professor of geology at Washington University, St. Louis. During the summer he is employed as geologist on the Missouri Geological Survey.

CECIL C. KILLINGSWORTH is a consulting engineering geologist at 1226 Selby Avenue, Westwood Village, Los Angeles, 24, California.

A. H. RABENSBURG, formerly with the Continental Oil Company, is chief geologist for John W. Mecom, independent oil operator, Gulf Building, Houston, 2, Texas.

C. C. ZIMMERMAN has resigned as assistant chief of the geophysical division of The Texas Company, Houston, to join the Keystone Exploration Company, 2813 Westheimer Road, Houston, Texas.

Lieutenant Commander ROGER REVELLE, of the Scripps Institution of Oceanography, La Jolla, California, is with the Bureau of Ships, Navy Department, Washington, D. C.

PETROLEUM GEOLOGISTS NEEDED IN GOVERNMENT WORK

America's production of petroleum must be kept ahead of the needs of the war effort. In this connection, the Government is seeking petroleum gelogists to aid in the search for new oil supplies.

Geologists are desired who are competent in the fields of stratigraphy, paleontology, and sedimentation. They will make field studies in most of the productive or potential oil areas of the United States including California, the Mid-Continent region, and the Appalachian region. Their work will be in the general field of geology including geologic mapping; the discrimination, measurement, and field tracing of stratigraphic units; the compilation of available subsurface data on the lithology, paleontology, and correlation of oil-bearing formations; and the preparation for publication of charts, diagrams, maps, and brief reports of the results of regional stratigraphic studies.

The positions pay $2,000 a year (plus $433 overtime pay) up to $4,600 a year (plus $628 overtime pay). The majority of openings are at the base salaries of $2,000 and $2,600 a year.

For the position of Junior Geologist, $2,000 a year plus authorized overtime, applicants are desired who have completed a 4-year college course leading to a bachelor's degree in geology or closely allied science, showing 30 semester hours of study in geology. Applications will be accepted from senior students, if otherwise qualified. For positions above the $2,000 level applicants should show in addition to the above a minimum of two years of professional experience in geology or appropriate graduate study. The amount and

character of the experience required beyond this minimum will vary with the duties and salary of the position for which the applicant is being considered. Applicants without complete formal education will be accepted if they have had sufficient qualifying experience.

The Civil Service Commission would appreciate your bringing this information to the attention of qualified persons whom you feel may be interested. Applicants should indicate the type of position desired as "Petroleum Geologist."

Application forms may be obtained from the Civil Service Commission, Washington, D. C. The form to be used is Standard Form No. 57 "Application for Federal Employment." For this particular purpose, it bears the identifying file numbers XT:AM:MBA. If other forms are used they should be similarly marked. Form 3630 for listing of pertinent college courses should be included with each application form.

Applications are not desired from persons using their highest skills in war work. Federal appointments are made in accordance with War Manpower Commission policies and directives and employment stabilization plans.

Major JEAN E. JOUJON-ROCHE is in the Corps of Engineers stationed at Fort Belvoir, Virginia.

Lieutenant-Colonel JOHN T. LONSDALE of Winfield, Iowa, is in the Anti-Aircraft Artillery at Manchester, Connecticut.

Ensign E. H. WENBERG, formerly with the Seismograph Service Corporation at Tulsa, Oklahoma, has graduated from the Naval School of Photographic Interpretation at Washington, D. C.

GLEN M. RUBY has been exploring for oil in Chile for many months. He writes from Santiago de Chile that an oil seep has been found south of Punta Arenas in Magellanes.

EDWARD A. FREDERICKSON, JR., formerly assistant professor of geology at the University of Oklahoma, is director of Ground School at Big Spring, Texas, Bombardier School.

GAYLORD FRAZIER, of the United States Geological Survey, Denver, Colorado, has been appointed secretary-treasurer of the Rocky Mountain Association of Petroleum Geologists, succeeding ROBERT E. SPRATT, who has been transferred to the Washington, D. C., office of the Survey.

FRANK B. NOTESTEIN has left The Texas Company at Caracas, Venezuela, and is in the Office of the Petroleum Administration for War, Foreign Division, New Interior Building, Washington, D. C.

WILBERT S. LARSON, JR., after a year of graduate work at the University of Iowa, has been employed by The Texas Company, New Orleans, Louisiana.

WILLIAM R. JOHNSON, recently in charge of the geological library at the University of Nebraska, has been employed by the Sun Oil Company, Dallas, Texas.

R. S. POWELL, acting division geologist for The Texas Company, Tulsa, has resigned to open a consulting office in Dallas, Texas.

CHARLES H. RANKIN, formerly with the Continental Oil Company, Denver, Colorado, has been retained as engineer by the Loco Hills Pressure Maintenance Association, Artesia, New Mexico.

MICHAEL ALLON, of Guthrie, Oklahoma, is with the Gulf Research and Development Company at Pitcher Creek, Alberta, Canada.

CHESTER W. COUSER is a major in the Air Corps with headquarters at Gravelly Point, Washington, D. C.

Major ALDEN W. FOSTER, of Pittsburgh, Pennsylvania, is temporarily stationed at Miami, Florida.

R. M. LARSEN is temporarily located at 3233 North Interior Building, Washington, D. C., with the Geological Survey, but expects to return to Wyoming by October.

FRANK S. PARKER, petroleum engineer and geologist for the Wilshire Oil Company, Inc., in California, for the past 3½ years, has resigned and opened offices for consulting work at 1941 Palmerston Place, Los Angeles. Parker has gained experience with the United States Geological Survey, the Shell Oil Company, and the Wilshire Oil Company.

HAROLD E. VOIGT, formerly geologist with the Phillips Petroleum Company in Houston, Texas, has joined the geological staff of the Superior Oil Company in Houston.

WALTER R. BERGER, JR., is a captain in the Ordnance Section of the Army.

STANLEY W. BLANCHARD, of the Standard Oil Company of Texas, has been transferred from Houston to Abilene, Texas, to represent the company in the Abilene district.

GEORGE DICKINSON may be addressed in care of the Shell Oil Company, 1008 West Sixth Street, Los Angeles, California.

Major MICHEL T. HALBOUTY has been transferred from the faculty of the Infantry School, Fort Benning, Georgia, and assigned to the Fuels and Lubricants Division, O.Q.M.G., Requirements Branch, as chief of the Field Estimate Section, Washington, D. C.

Lieutenant-Colonel HARRY W. MCCOBB may be addressed at the Area Petroleum Office, A.P.O. 887, New York, N. Y.

A. ALLEN WEYMOUTH, of the New Zealand Petroleum Company, Gisborne, New Zealand, has changed his address to 2432 First Avenue North, Seattle, Washington.

M. H. S. BARKER, formerly with the United British Oilfields of Trinidad, Ltd., Trinidad, has arrived in England and has been appointed to the Ministry of Economic Warfare, London.

OKLAHOMA

PENNSYLVANIA

TEXAS

TEXAS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - Ralph D. Copley
The California Company
1st Vice-President - - - - - - C. E. Erdmann
U. S. Geological Survey
2nd Vice-President - - - - - - John E. Blixt
The Texas Company
Secretary-Treasurer - - - - - Gaylord Frazier
U. S. Geological Survey, 208 Custom House

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - Darsie A. Green
The Pure Oil Company, Box 311, Olney

Vice-President - - - - - - - Clark T. Snider
Lario Oil and Gas Company, Mt. Vernon

Secretary-Treasurer - - - - - - Fred H. Moore
Magnolia Petroleum Corp., Box 535, Mt. Vernon

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - Richard S. Hicklin
Carter Oil Company

Vice-President - - - - - - - Charles J. Hoke
Phillips Petroleum Company

Secretary-Treasurer - - - - - Robert F. Eberle
The Superior Oil Company

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - E. P. Philbrick
Magnolia Petroleum Company
Vice-President - - - - - - - Jack M. Copass
Amerada Petroleum Corp., Box 995
Secretary-Treasurer - - - Robert B. McNeely
209 Ellis-Singleton Building
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - - J. W. Hoover
The California Co., 1818 Canal Bldg.
Vice-President - - - - - - - - H. C. Petersen
Freeport Sulphur Co., American Bank Bldg.
Secretary-Treasurer - - - - - W. J. Gillingham
Schlumberger Well Surveying Corporation
452 Canal Bldg.

Meets the first Monday of every month, 7:30 P.M., St. Charles Hotel. Special meetings by announcement.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - G. D. Thomas
Shell Oil Company, Inc.
Vice-President - - - - - - - R. M. Wilson
Ohio Oil Company
Secretary-Treasurer - - - - - - T. H. Philpott
Carter Oil Company, Drawer 1739

Meets the first Monday of every month, October to May, inclusive, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - H. E. McGlasson
Stanolind Oil and Gas Company
Vice-President - - - - - - - - - C. B. Roach
Shell Oil Company, Inc.
Secretary - - - - - - - - - - A. L. Morrow
Magnolia Petroleum Company
Treasurer - - - - - - - - - D. N. Rockwood
Union Producing Company

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - George D. Lindberg
Sun Oil Company, Toledo, Ohio
Vice-President - - - - Edward J. Baltrusaitis
Gulf Refining Company, Box 811, Saginaw
Secretary-Treasurer - - - - Mrs. Lucille Esch
State Geological Survey, Lansing
Business Manager - - - - - - William Schulz
Cities Service Oil Co., Mt. Pleasant

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - David C. Harrell
Carter Oil Company, Box 1490

Vice-President - - - - - - - L. R. McFarland
Magnolia Petroleum Company
508 Millsaps Building

Secretary-Treasurer - - - - - K. K. Spooner
The Atlantic Refining Company, Box 2407

Meetings: First and third Wednesdays of each month from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - - C. C. Hannum
The Texas Company

Vice-President - - - - - - - - - J. P. Gill
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - J. M. Westheimer
Samedan Oil Corporation, Box 959

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - H. Travis Brown
Cities Service Oil Company, Box 4577

Vice-President - - - - - - Lester L. Whiting
The Texas Company, Box 354

Secretary-Treasurer - - - - - - I. Curtis Hicks
Phillips Petroleum Company
1211 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every Thursday, at 12:00 noon, Skirvin Hotel Coffee Shop.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - Grant W. Spangler
Stanolind Oil and Gas Company

Vice-President - - - - - - Edwin A. Dawson
1829 N. Broadway

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - Robert E. Garrett
Consulting Geologist, 301 Beacon Building

1st Vice-President - - - - - - - J. V. Howell
912 Philtower

2nd Vice-President - - - - - - - Jerry E. Upp
Amerada Petroleum Corporation

Secretary-Treasurer - - - - - - James A. Price
W. C. McBride, Inc., 625 Wright Bldg.

Editor - - - - - - - - - - - Roy L. Ginter
Ginter Laboratory

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - Frith C. Owens
Consulting, Nixon Building

Vice-President - - - - - - - - E. D. Pressler
Humble Oil and Refining Company, Box 1271

Secretary-Treasurer - - - John Bruce Scrafford
Consulting, Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - S. A. Thompson
Magnolia Petroleum Co., P. O. Box 900

Vice-President - - - - - Joseph M. Wilson
Continental Building

Secretary-Treasurer - - - - - - Robert I. Seale
Schlumberger Well Surveying Corporation
1004 Continental Building

Executive Committee - - - - - - T. K. Knox
Republic Natural Gas Co., Houseman Bldg.

Meetings: Regular luncheons, first Monday of each month, 12:00 noon, Petroleum Club, Adolphus Hotel. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - - E. B. Wilson
Sun Oil Company

Vice-President - - - - - Laurence Brundall

Secretary-Treasurer - - - - - - - B. W. Allen
Gulf Oil Corporation

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - Donald M. Davis
Pure Oil Company

Vice-President - - - - - Carl B. Richardson
Barnsdall Oil Company

Secretary - - - - - - - - Hillard W. Carey
Houston Natural Gas Corp., Box 1188

Treasurer - - - - - - William F. Calohan
British-American Oil Producing Company

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - Wm. H. Spice, Jr.
Consulting, 2101 Alamo National Building

Vice-President - - - - - Harvey Whitaker
Consulting, 1409 Milam Building

Secretary-Treasurer - - - - Arthur H. Petsch
The Ohio Oil Co., 1417 Milam Building

Meetings: Third Tuesday of each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - Karl A. Mygdal
The Pure Oil Company, Box 2107

Vice-President - - - - William J. Hilseweck
Gulf Oil Corporation

Secretary-Treasurer - - - Richard H. Schweers
The Texas Company, Box 1720

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - Dan D. Heninger
The Ohio Oil Company, 615 Hamilton Bldg.

Vice-President - - - - - - Dolph E. Simic
Cities Service Oil Co.

Secretary-Treasurer - - - Carlos M. Ferguson
Magnolia Petroleum Co., 500 Waggoner Bldg.

Luncheons and evening programs will be announced.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - - Fred H. Wilcox
Magnolia Petroleum Company

Vice-President - - - - - - Prentiss D. Moore
Moore Exploration Company

Secretary-Treasurer - - - - - - Dana M. Secor
Atlantic Refining Company

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 1473

Vice-President - - - - - - - - H. J. Wagner
Public Service Commission

Secretary-Treasurer - - - - - - Cramon Stanton
United Carbon Company, Box 1913

Editor - - - - - - - - - Robert C. Lafferty
In Service (Navy)

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Vice-President - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston, Texas

Editor - - - - - - - - - - - - J. A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma

Secretary-Treasurer - - - - - - - Hart Brown
Brown Geophysical Company, Box 6005
Houston, Texas

Past-President - - - - - - - Frank Goldstone
Shell Oil Company, Inc., Houston, Texas

Business Manager - - - - - - - - J. F. Gallie
P.O. Box 1925, Washington, D.C.

Volume 27 SEPTEMBER, 1943 Number 9

BULLETIN

of the

American Association *of* Petroleum Geologists

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BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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CLAIMS FOR NON-RECEIPT of preceding numbers of THE BULLETIN must be sent Association headquarters within three months of the date of publication in order to be filled gratis.

BACK NUMBERS OF THE BULLETIN, as available, can be ordered from Association headquarters. Cloth-bound Vols. 11 (1927) to 15 (1931), each $6.00; Vols. 22 (1938) to 24 (1940) and Vol. 26 (1942), each $17.00. Separate numbers, and a few nearly complete sets are available. Descriptive price list sent on request. Special prices to members and associates. Discounts to libraries. *Geology of Natural Gas* (1935), $6.00 ($4.50 to members and associates). *Geology of Tampico Region, Mexico* (1936), $4.50 ($3.50 to members and associates). *Gulf Coast Oil Fields* (1936), $4.00 ($3.00 to members and associates). *Miocene Stratigraphy of California* (1938), $5.00 ($4.50 to members and associates). *Stratigraphic Type Oil Fields* (1941), $5.50 ($4.50 to members and associates). *Source Beds of Petroleum* (1942), $4.50 ($3.50 to members and associates). *Permian of West Texas and Southeastern New Mexico* (1942), $2.00 ($1.50 to members and associates). *Petroleum Discovery Methods* (1942), $1.00.

THE BULLETIN gives senior authors 35 reprints of major papers. Additional reprints, in limited numbers, and for private distribution, are furnished at cost, if orders accompany corrected galley proof.

Association Headquarters—708 Wright Building, 115 and 117 West Third Street, Tulsa, 1, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

BOX 979

TULSA, 1, OKLAHOMA

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THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.

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SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Organized, March, 1927; affiliated, March, 1928; chartered, technical division, April, 1930)
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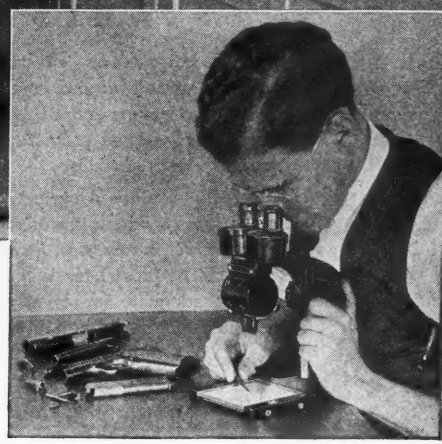

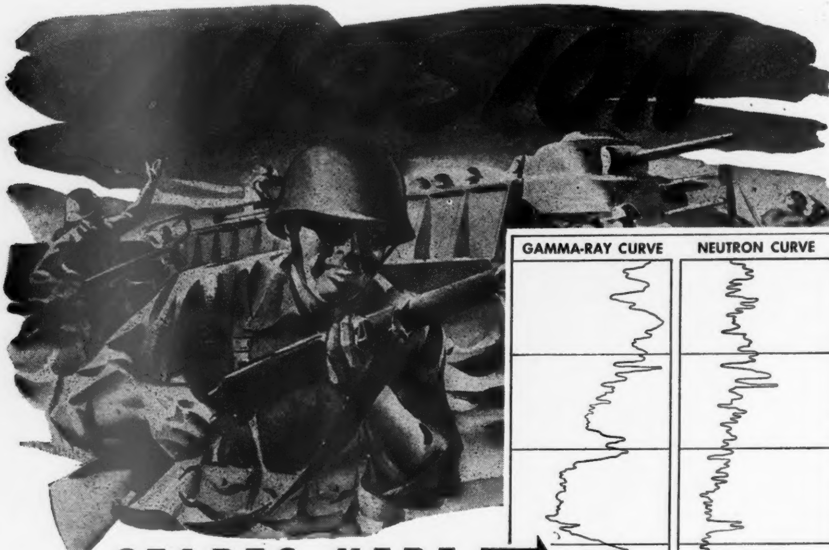

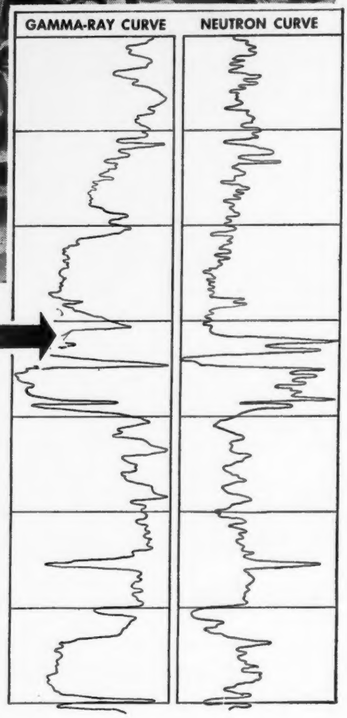
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